March 2007

Upperclassmen Dormitory Design

Chase W. Terrio
Worcester Polytechnic Institute

James V. Scully
Worcester Polytechnic Institute

Michael Hansen
Worcester Polytechnic Institute

Project Number: LDA-0701

Upperclassmen Dormitory Design

A Major Qualifying Project Report:

Submitted to the Faculty of the

Worcester Polytechnic Institute

In partial fulfillment for the requirement for the

Degree of Bachelor of Science

By

____

Michael Hansen

____

James Scully

____

Chase Terrio

Date: March 1, 2007

Approved:

____

Professor L. D. Albano, Major Advisor

Abstract

This MQP project focused on the design of a four story apartment style residence hall intended for upper-classman. Three building designs were developed using steel, concrete, and a composite of steel and concrete. Based on cost, the team selected the steel structural system to design the atypical areas and analyze lateral forces. A construction cost estimate of the building was developed using 16 CSI divisions. An additional cost estimate was developed to incorporate LEED certification.

Authorship

Abstract		
Authorship		
1.	Introduction	
2.	Background	
3.	Methodology	
3.1.	Design of Concrete Systems	Mike Hansen
3.2.	Design of Structural Steel Systems	James Scully
3.3.	Design of Composite Steel and Concrete Systems	Chase Terrio
3.4.	Design of Lateral Load-resisting System	James Scully
3.5.	Design of Atypical Areas	James Scully
3.6.	Development of Building Cost Estimates	Mike Hansen
3.7.	Development of LEED Building Cost Estimate	Chase Terrio
4.	Analysis	
4.1.	Analysis of Concrete Systems	Mike Hansen
4.2	Analysis of Structural Steel Systems	James Scully
4.3	Analysis of Composite Steel and Concrete Systems	Chase Terrio
4.4	Analysis of Lateral Load-resisting Systems	James Scully
4.5	Analysis of Atypical Areas	James Scully
4.6	Analysis of Building Cost Estimates	Mike Hansen
4.7	Analysis of LEED Building Cost Estimate	Chase Terrio
5	Conclusion	
I.	Appendix	
A.	Structural System Design	
B.	Cost Estimates	
C.	LEED Certification & Cost	
D.	Lot Location	
E.	References	

Abstract, Authorship, Introduction, Background, Methodology, Analysis, and Conclusion were developed through equal effort from all members.

Table of Contents

Abstract 2
Authorship 3
1. Introduction 7
2. Background 10
3. Methodology 16
    3.1. Design of Concrete Systems 20
    3.2. Design of Structural Steel Systems 23
    3.3. Design of Composite Steel and Concrete Systems 25
    3.4. Design of Lateral Load-resisting System 27
    3.5. Design of Atypical Areas 29
    3.6. Development of Building Cost Estimates 30
    3.7. Development of LEED Building Cost Estimate 32
4. Analysis 33
    4.1. Analysis of Concrete Systems 34
    4.2. Analysis of Structural Steel Systems 38
    4.3 Analysis of Composite Steel and Concrete Systems 43
    4.4 Analysis of Lateral Load-resisting Systems 47
    4.5 Analysis of Atypical Areas 48
    4.6 Analysis of Building Cost Estimates 49
    4.7 Analysis of LEED Building Cost Estimate 51
5 Conclusion 54
I. Appendix 56
    A. Proposal 56
    B. Structural System Design 58
    C. Cost Estimates 79
    D. LEED Certification & Cost 88
    E. Lot Location 92
    References 95

Table of Tables

Table 1: Common Dead Loads 18
Table 2: Common Live Loads 18
Table 3: Cost of Steel by Weight 37
Table 4: Total Cost by Method 37
Table 5: Scheme 1 Results 38
Table 6: Scheme 2 Results 39
Table 7: Scheme 3 Results 40
Table 8: Column Design Results 40
Table 9: Structural Layout Costs 41
Table 10: Scheme to Slab Relationship 44
Table 11: Scheme Costs 45
Table 12: Atypical Design Results 48
Table 13: LEED Silver Certification Options 52
Table 14: Roof Columns 58
Table 15: 3rd Floor Columns 60
Table 16: 2nd Floor Columns 61
Table 17: 1st Floor Columns 62
Table 18: Girder Loads 63
Table 19: Beam Loads 63
Table 20: Girder Design 64
Table 21: Beam Design 65
Table 22: Beam Design Volumes (Cu. Inch) 66
Table 23: Girder Design Volumes (Cu. Inch) 67
Table 24: Column Design Volumes (Cu. Inch) 68
Table 25: Steel Interior Beam Design 69
Table 26: Steel Roof Beam Design 70
Table 27: Atypical Roof Design 71
Table 28: Atypical Interior Level Design 72
Table 29: Substructure Cost (Volume) 79
Table 30: Cost Breakdown by CSI Division 80
Table 31: Final Cost Analysis 87
Table 32: LEED Points 90
Table 33: LEED Cost Analysis 91

Table of Figures

Figure 1: Site Location........ 11
Figure 2: Property Line........ 12
Figure 3: Columns spaced 40'x20' 17
Figure 4: Columns spaced 20'x20' 17
Figure 5: Columns spaced 10'x20' 17
Figure 6: Typical Frame........ 28
Figure 7: Atypical Floor Plan 29
Figure 8: Unit Design Layout 1 34
Figure 9: Unit Layout Design 2 35
Figure 10: Unit Layout Design 3 36
Figure 11: Column Spacing Option 39
Figure 12: 10 ft Beam Spacing 42
Figure 13: Cost Breakdown by Division 50
Figure 14: Topographical Map 92
Figure 15: Floor Plan Layout........ 93
Figure 16: Site Plan Layout 94

1. Introduction

Worcester Polytechnic Institute has a desire to increase the percentage of upperclassmen living on campus, but do not have the necessary housing facilities. Residential Services believes that seniors and juniors could provide valuable leadership skills and be role models for the freshman and sophomore students, as well as contribute to security. Currently, the opportunity for upperclassmen to live on campus is small, and the majority of upper-class students live in off-campus apartments, in the nearby neighborhoods of Worcester. Often students can find more desirable housing in the off-campus apartments such as individual bedrooms and more affordable rates. The Greek system also houses a significant number of upper-class students.

Worcester Polytechnic Institute is now making a serious effort to increase the numbers of upperclassmen living on campus. For example, a project is currently being planned for construction next to the existing Founders hall. It is scheduled for completion in fall 2008. The focus of this Major Qualifying Project is to design an independent interpretation of a potential residence hall on campus that will be appealing to upper-class students.

After speaking with Naomi Letendre, the Director of Residential Services, it became clear that Worcester Polytechnic Institute planned to use currently owned property and not acquire new land in the development of new dormitories. One example of this philosophy is the proposed development of the new residence hall between Boynton St. and Dean St. Other options for the new dorm include a new piece of land on 23 Trowbridge Road, which was obtained by WPI at the end of 2003. This piece of land was a grant given by Mr. Ersckin. The lot is between Trowbridge Road and Einhorn Street and is about 50,000 square feet. The shape of the lot and its size will influence the design of the building.

The goal of this project was to develop a new residence hall on 23 Trowbridge Road. Before the design began, Worcester zoning bylaws and *Massachusetts State Building Codes* were examined. The Worcester Zoning Codes provided building set back restrictions and height limitations for the dormitory. The Massachusetts State Building Codes provided loading conditions for live loads, snow loads, and wind loads. Then we developed a preliminary design using three structural options including concrete, steel, and a composite design of the two. Once a structural option was chosen, it was then used to design the Atypical areas of the building. Along with the structural design, a cost estimate for the project was calculated. The first cost was for the entire building, and a second cost was developed to meet LEED certification requirements. The subsequent chapters will discuss in more detail the development of the design, analysis, and cost of this independent residence hall.

This MQP is designed to fulfill capstone requirements through the applied manifestation of various previous course studies and assignments. The techniques utilized in this project were developed through a host of WPI CEE courses. They include, but are not limited to; the Design of Steel Structures, Design of Reinforced Concrete Structures, Construction Project Management, and Cost Estimating. The skills acquired through these courses were applied to develop a unique and individual project scope and design.

In an effort to fill Worcester Polytechnic Institute's need for a new residence hall and the availability of 23 Trowbridge, as the potential location for a future dormitory, this Major Qualifying Project will design a building for this lot.

2. Background

The project team decided to develop a new dormitory located on campus. This required discussions with John Miller, the Director of Plant Services, and Naomi Letendre, the Director of Residential Services, to establish a building location and design criteria. In addition to those meetings, research was done on the Worcester zoning bylaws and certain provisions of the *Massachusetts State Building Codes*. Previous knowledge of an empty lot on Trowbridge Rd. allowed for preliminary site investigations.

John Miller is the Director of Plant Services and is responsible for the management of all WPI property. His office provided the topographic layout and plan view of the lot which is located at 23 Trowbridge Rd. It was last surveyed in 2004. From these plans, the team was able to establish the dimensions of the property. A working knowledge of the property's history, including the previous layout of the property, was also developed primarily through Mr. Miller. The following figures show the site location and the property lines of the site.

Figure 1: Site Location

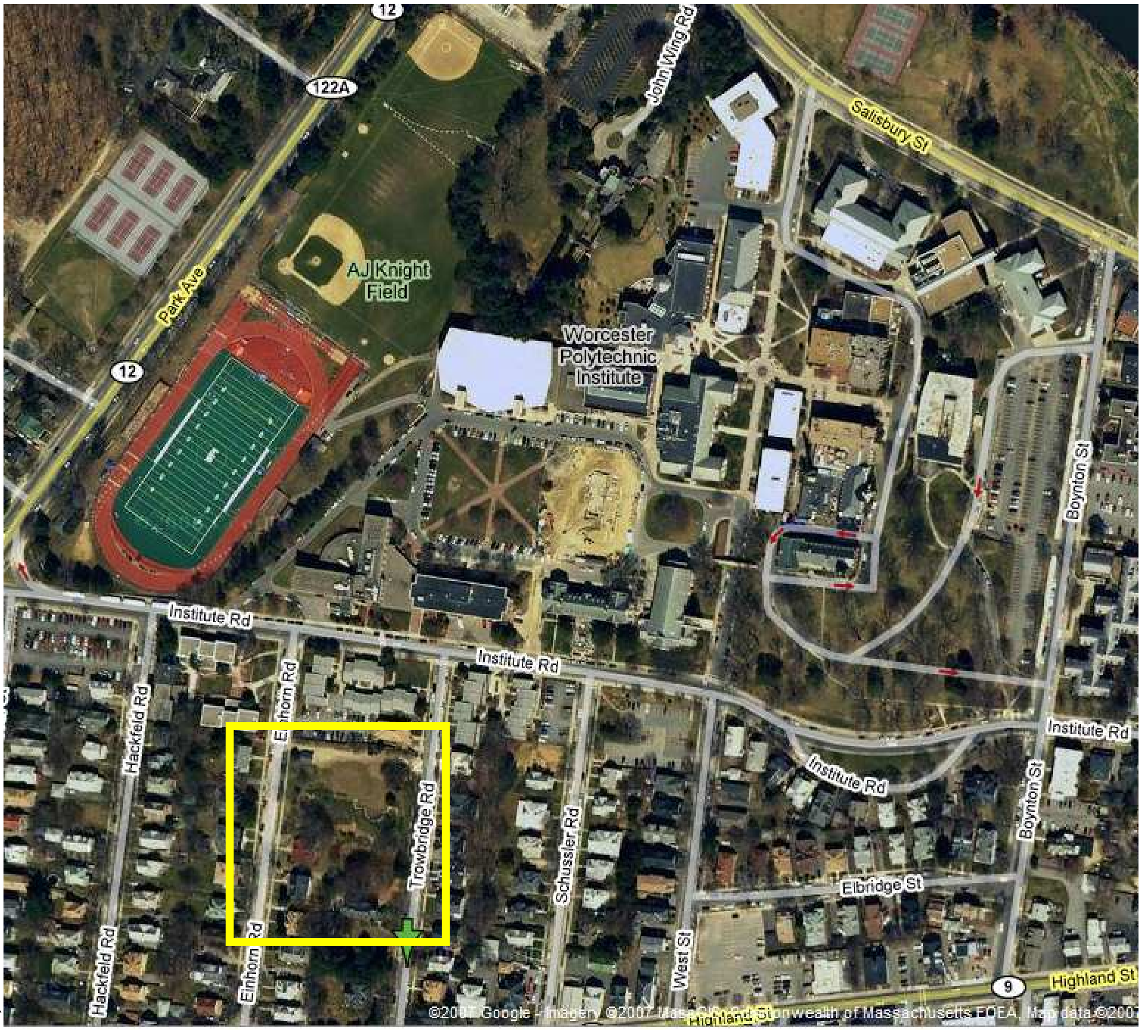
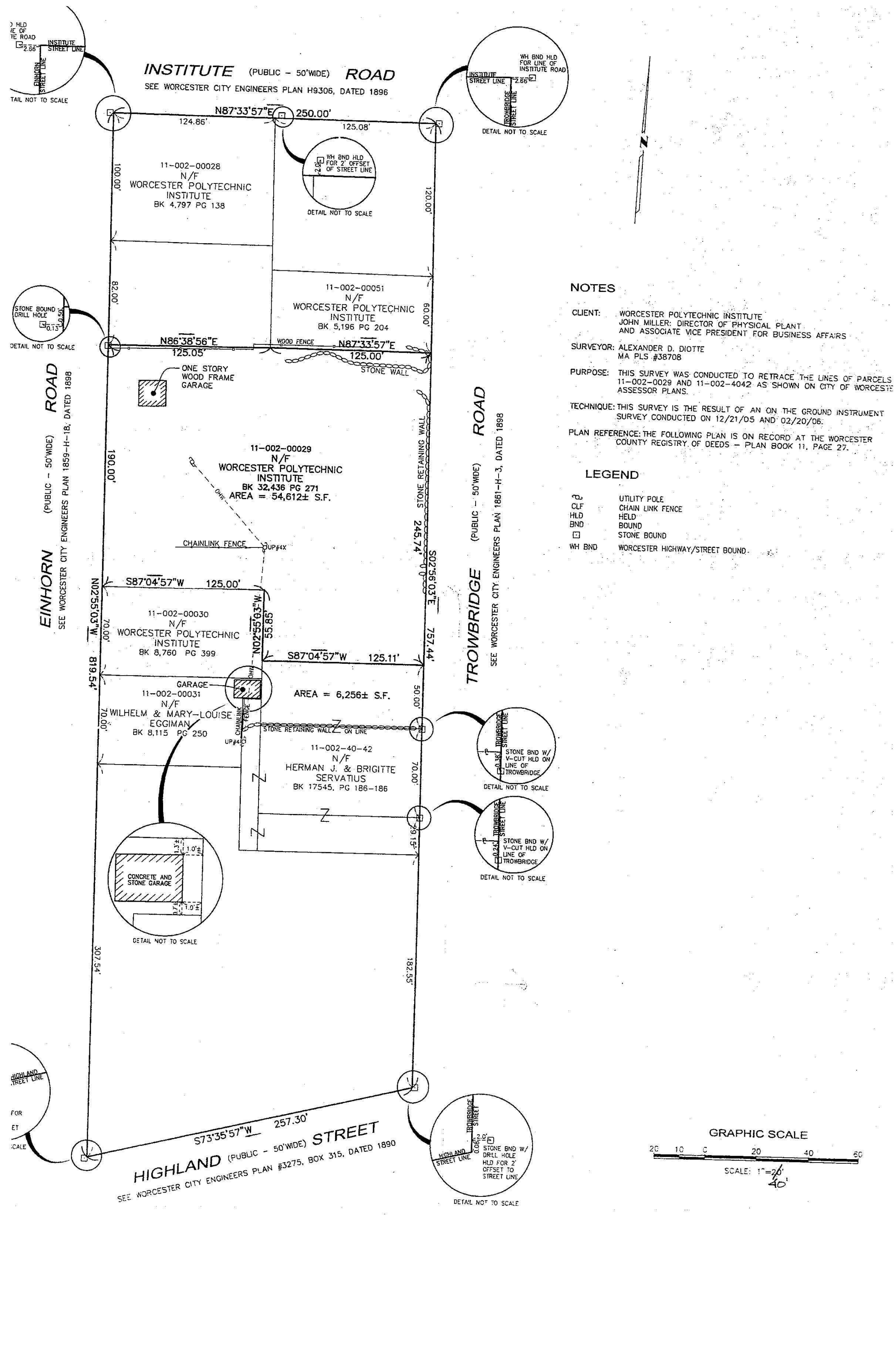


Figure 2: Property Line



The property is a double frontage lot located between Einhorne and Trowbridge Rd. The property was given to WPI through a grant in December, 2003 by Mr. Ersckin after the death of his wife. A mansion stood on the property, but it was demolished just prior to WPI's acquisition. Due to the previous existence of the mansion a fair portion of the lot is graded and mostly level. This portion of the lot is the portion closest to Institute Road and the WPI campus. Beyond this relatively level portion of the lot, the remaining area is rather steep with an elevation drop of nearly 40 feet over a distance of roughly 120 feet. The exact location can be seen in the map provided in Appendix section E.

Initial site investigation of 23 Trowbridge Rd. allowed the project team to gain a sense of proportion for the size and shape of the property. For instance, the upper portion of the site was discovered to be rather large. The two curb cuts for the lot were also located in the upper portion of the lot, one on each fronting street. The site visit allowed for a more accurate visualization of possible building options. The unique property characteristics required creativity in terms of design and shape of the building. The property's shape, geographic constraints, and orientation would all be traits that were identified as influences on the ultimate design.

Following the team's site investigation, a meeting with Naomi Letendre, the Director of Residential Services, was scheduled to develop a better understanding of desirable features and living conditions that students typically look for in upperclassmen housing. Mrs. Letendre spoke about WPI's goal to develop more on-campus housing for upper classmen and the type of housing in which students were typically interested. Apartment style living was a more popular approach and common features include: single bedrooms, full kitchens and a living room. These features were incorporated into the conceptual layout and influenced the dimensions of a typical apartment unit. Mrs. Letendre also indicated a desire to house between 100 and 200 students in a future dormitory. This number also influenced our design.

One real life constraint on the Trowbridge property are the current zoning bylaws governing the property. The team went to the Worcester Zoning Department office and determined that the property was governed by residential requirements. This meant set backs of 15 feet from both streets and a side yard set back of 10 feet, in addition to a height limitation of 50 feet. Though the residential building envelope would be used in the design of our dormitory, a variance for use would be needed to build a dormitory on the lot. This would result in the property being governed by a different set of dimensional restrictions and criteria most likely being Institutional, a designation for universities. The project team assumed that the variance would be approved, allowing the property to be governed by the neighboring zoning requirements for academic housing. The appeal would have to be approved by the Worcester Zoning Board of Appeals through a public hearing that is publicly advertised and scheduled on the appeals board agenda. The team's research of the *Massachusetts State Building Code* determined loading conditions for the Worcester region. Dead loads, live loads, and snow loads were established based on the *Massachusetts State Building Code* to be used for design calculations.

WPI has repeatedly communicated their plan for a large amount of construction to take place over the next 5 to 10 years, including the new construction and renovation of athletic fields and facilities, administrative buildings, and housing facilities. WPI has also expressed a desire to go green as seen through their efforts to obtain LEED certification for the new Bartlett Center. Also, a new on-campus upperclassmen housing facility is being planned for completion in fall 2008, and it too will be LEED silver certified. LEED stands for Leadership in Energy and Environmental Design. The U.S. Green Building Council is the organization that awards certifications. They also establish the list of criteria that a building must comply with in order to be certified. Depending on how compliant with the LEED criteria a building is, a different level of certification will be awarded ranging from certified through silver, gold, and platinum. Because of this desire to "go green", we too are planning to include design options in our building that would allow for LEED certification.

3. Methodology

To develop a design for the proposed dormitory, the permissible building envelope was first established. This was defined through obtaining the plot plan and examining the Worcester zoning bylaws which dictate set backs and height limitations: 15 feet from the street, 10 feet for each side yard, and 50 feet height limit. This determined the building dimension constraints. Knowing the available envelope and constraints, a footprint and height restriction for the structure were established. From there, a typical apartment unit was established. A single unit is composed of two floors with four bedrooms and a bathroom upstairs. The kitchen, common room, and living area is located on the first floor with an internal staircase linking the two floors. Each floor also has a portion of community space available to all residents. These spaces are used for various activities ranging from laundry service, computer labs, entertainment room, and study areas. This is also where the central stair well and elevator services are housed. The total number of units that fit within the permissible building envelope was determined to be 24 with a total occupancy of 96 students.

Several different structural layouts were established to explore the costs of the designs for the building. Each of these standard layouts were analyzed for gravity loads using three design methods: steel, concrete, and a composite of steel and concrete. The figures below illustrate the three main structural layouts that were analyzed.

Figure 3: Columns spaced 40'x20'

Figure 4: Columns spaced 20'x20'

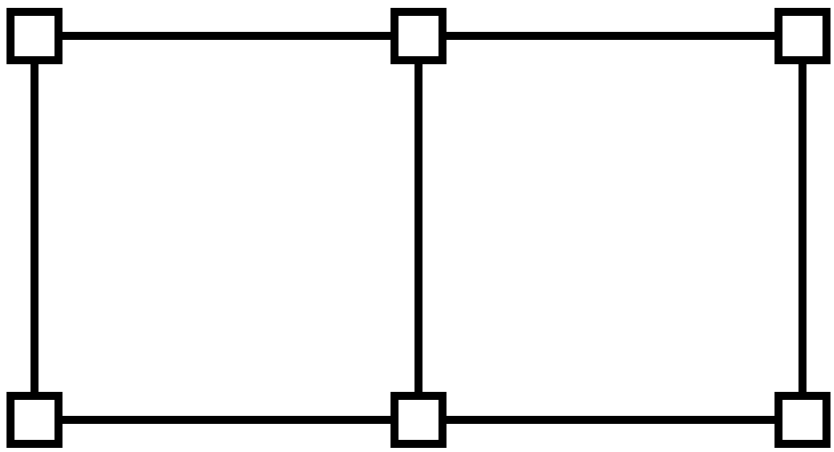
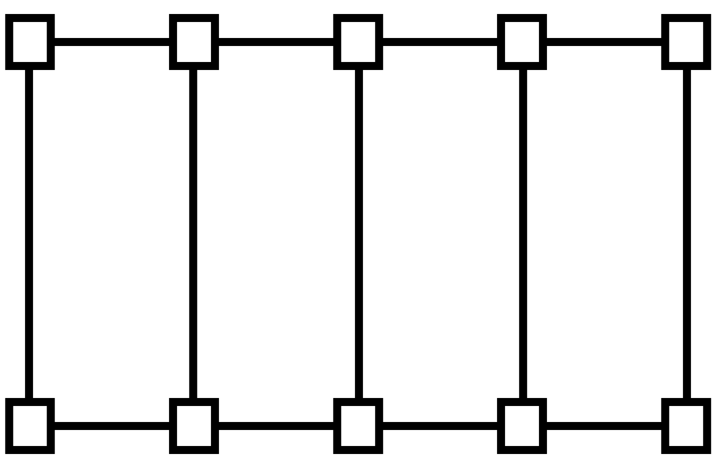


Figure 5: Columns spaced 10'x20'



The uniform loading conditions for each of the three design methods analyzed are consistent with the minimum load requirements stated in *Massachusetts State Building Code*. The Code outlines minimum criteria for dead loads, live loads, and snow loads for the region in which we are constructing as well as the type of building being built. These loading conditions are outlined below in Tables 1 and 2.

Table 1: Common Dead Loads

Common Dead Loads	Intensity
Concrete	150 pcf
Movable Steel partitions	4 psf
Suspended Ceiling	2psf
Hardwood Flooring	4 psf
MEP	5 psf
Waterproofing	5 psf

Table 2: Common Live Loads

Common Live Loads	Intensity
Dwelling units	40 psf
Public rooms	100 psf
Corridors	80 psf
Snow Load	35 psf

Structural design and analysis studies were performed on the possible layouts under each design material for a single, typical interior unit. All unit costs were developed based on these analyses and the design requirements. This single unit included the roof level and subsequent levels in one 40’x20’ column of rooms (a stack of two apartments).

Following the initial designs for gravity loads and cost analyses of the various layouts using the three design methods, one design layout and method was selected for continued study and development. The criteria for selecting the best design established: 36” or less between each floor of the building, the deflection of the floor be less then the length of the span of the beam over 360 (L/360), and the method selected would result in the lowest construction cost.

Using these three criteria, a method was selected to continue the analysis of lateral loading and the atypical design areas. Risa 2D software was used to calculate the effects of lateral loads on the building structure which were then compared to design capacities of the structural frame. Following the lateral load analysis was the design of the atypical areas within the floor plan for gravity loads. Sections 3.1 through 3.7 provide greater detail on the development and analysis of the building.

3.1. Design of Concrete Systems

The building was looked at with the consideration of being built using all reinforced concrete for the structural beams, girders, and columns. The major factors that were used as the guidelines for the design were the moments on each of the beams and girders and the overall deflection of the members. The moments were calculated based on the live loads and dead loads appropriate to the conditions of our building. The influence of the spacing of the columns and the layout of the beams and girders was explored The calculations for the size of the members were looked at for several different layouts and the best design was selected based on criteria chosen by the group based on building design codes. Our criteria were based on a floor height of no greater than 36”, a deflection no greater than L/360, and the functional placement and sizes of both columns and beams. However, there were certain assumptions that had to be made. For the sake of this design, all members were assumed to be simply supported and the codes for building were based on the ACI standards. Our textbook from Concrete follows equations that are consistent with that of the ACI, and our concrete analysis was done using these requirements.

The beams and girders were designed in a similar fashion. The positive and negative moments in the beam were calculated so that the appropriate cross sectional dimensions and reinforcing steel could be defined to support the loads. The positive moment was determined in several steps. The flange width of the beams was found based on the beam spacing. The next step was to determine the height of the T-Beam and the appropriate location for the steel reinforcement in the web. The area of steel was found and compared with the minimum area of steel required for our member. The amount of steel in the design exceeded the minimum steel that was required. Next the beam was checked to ensure that the flange was tension controlled. The flange was tension controlled, and the moment was found based on the information in the previous steps. The negative moment was found using the same steps, except that the sizes were based on the web of the beam and not the flange in this case. The compression zone was found in the base of the web and if the compression zone was able to withstand the forces without demonstrating any failures based on the amount of steel selected for it, then the final negative moment could be calculated.

The steps for computing the size and strength of the columns do not vary much from the steps that were used in the beam process. The first step was to compute the factored loads and moments (appendix A for example calculations) based on the dead and live loads on each floor. A slightly different column size was used on each floor due to the extra loads from the floors above. An alternative solution was to use the same size column with varying amounts of rebar for each floor based on the design loads. This was not used because the size of the columns did not affect the usable floor space. Next, the column size was estimated and checked to see if the column was too slender for the given loads. Slenderness is tested because some columns are often unable to withstand the moments that are exerted on them and sometimes fail due to their length to thickness ratio. This is why the column must be wider to resist this type of failure. If it was in fact too slender, then the column would have failed. Next there was a check to determine if the moments met the minimum moment requirements. From this step the EI was calculated, where EI stands for the flexural stiffness of the column based on the steel reinforcement in the column. Once this was found, the magnified moments on the columns were determined. The ability of the columns to exceed the calculated moments is what was ultimately important in ensuring safety in the system. They were designed to be able to withstand the combined axial and bending loads without any structural failure.

3.2. Design of Structural Steel Systems

The steel design for the housing project was based on the LRFD method outlined in the *AISC Steel Construction Manual*. The steel design was completed in three sections. The first component was the design of the roof level. Second was the design of a typical interior level. The third was the design of columns for the four levels in the structure.

The design loads for the roof were examined for different layout options. The layouts in the roof level are similar to the layouts in the interior levels. Three different column spacing scenarios were considered for the floor plan. Each of those scenarios were further studied for various beam span and spacing options. Spreadsheets developed in Excel assisted in repetitive calculations. Beams and girders were chosen from the list of W-shape wide flange sections. For each scenario, the lightest shape that met both the floor depth and deflection criteria was selected.

Column design followed similar steps to those taken during the beam and girder design. The three column spacing alternatives were examined for one typical bay in the structure. The tributary area carried by a column was the driving factor for the selection of column sizes. Columns were selected on a level by level basis for a typical bay.

With the lightest girder, beam, and column selected for each respective scenario, the different alternatives were compared to one another. The goal was to determine if using multiple, smaller beams or if using fewer, larger beams provided the more cost effective strategy. For all of the alternatives a cost estimate was generated for a typical bay including the roof level, three interior levels, and all of the columns in the bay. A 5 inch thick concrete slab was assumed to be in all scenarios and a differential cost estimate was calculated. Although, each alternative was a viable option, the most economical solution was preferred.

3.3. Design of Composite Steel and Concrete Systems

The composite design was based on examples from McCormac and Nelson's third edition of *Structural Steel Design using the LRFD method*. Looking at the beam span and spacing scenario's outlined above, slab thickness was determined using the depth-span ratio of L/24. If the ratio resulted in a slab larger than six inches that design scenario would not work due to the limit of the available strength in flexure tables for composite sections in the AISC design manual. This inadequacy of the table is due to the loading conditions present in the building requiring relatively small beams in composite sections. This also eliminated scenario's that required beams spaced excessively far apart such as a 40 foot span spaced 20 feet apart.

When compatible scenarios were established based on the slab criteria, LRFD analysis was done assuming unshored construction and assembly. Using this analysis, a uniform beam and girder were designed for the roof and the roof loading conditions. Additionally typical beams and girders are designed for the interior floors and their respective loading conditions. As the spacing and span lengths of the beams and girders were changed for each scenario, an effort was made to identify repeating loading conditions throughout the structure as well as repeating requirements for certain W-shape sections for those loads. In other words, as beam and girder spacing changed, scenario's would be repeated resulting in the same loading magnitudes on the same beam under different placement options.

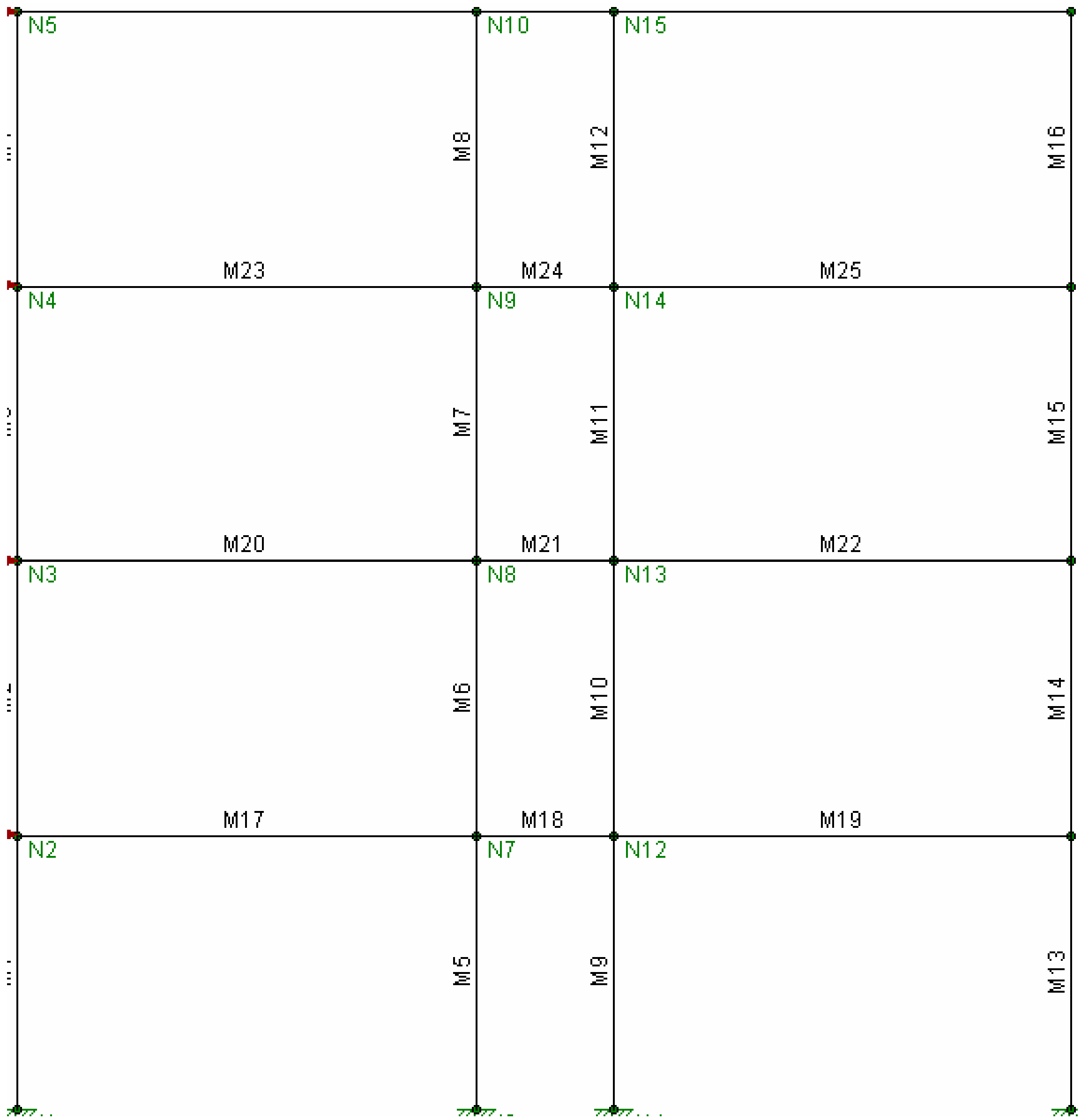
Following the completion of analysis and design for each design scenario, a cost estimate was calculated based on tonnage of steel and cubic yards of concrete. The linear footage of steel required by each scenario was determined, and the tonnage of steel associated with that linear footage was calculated. In addition, the required cubic yards of concrete was determined based on the required slab thickness for each scenario. Ultimately the most effective scenario was determined by cost and the other criteria outlined in the above sections.

3.4. Design of Lateral Load-resisting System

Once the economical structural system was determined, then lateral wind loads were examined to determine the selected system is adequate. The intensity of the wind load came from the Massachusetts State Building Codes for Zone 2 and Exposure B. For a building less than 50 feet, the wind load is 17 pounds per square foot.

A common frame of the structure is modeled in RISA-2D Educational Version. A typical frame includes 3 bays and 4 floors. Two of the bays are rooms and the center bay is the hallway of the building. The room bays are 20 feet wide and the hallway is 6 feet wide. Each column is 12 feet tall, with the total height of the building being 48 feet tall. The figure below displays a side view of a typical frame.

Figure 6: Typical Frame

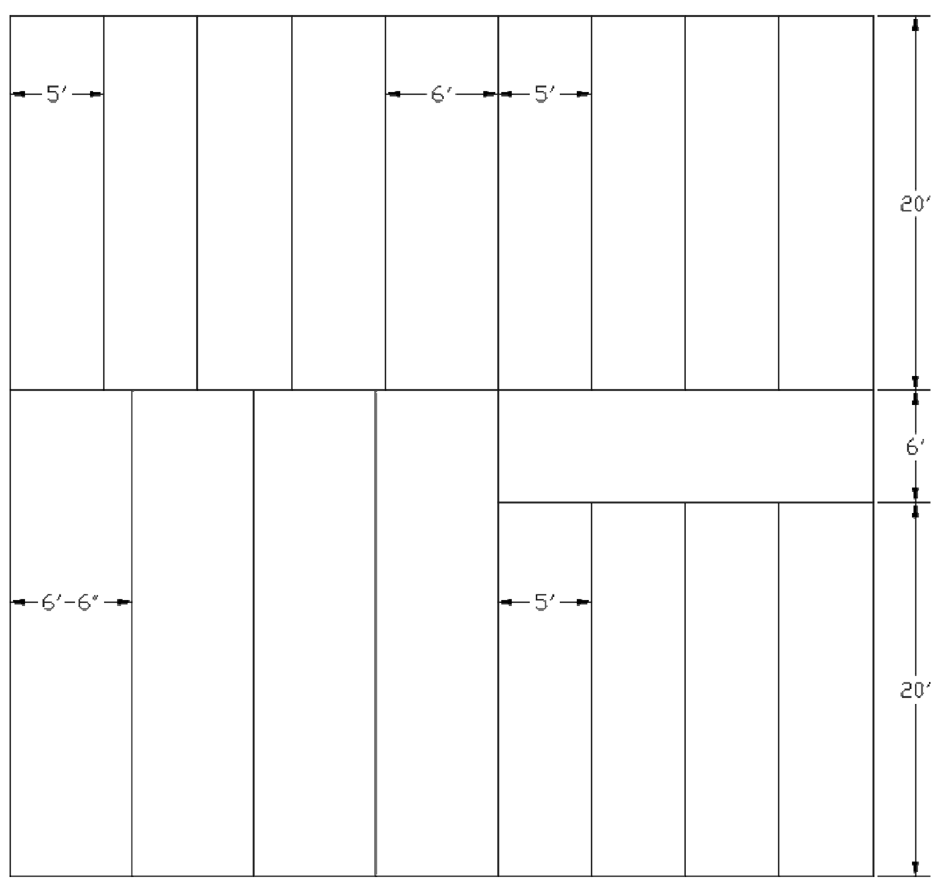


The length of the building is divided by the number of frames to determine the area used in the model. Then the 17 psf wind load is applied as a distributed load on one side of the frame. The stresses in the members and overall sway of each level are measured.

3.5. Design of Atypical Areas

With the designs of the typical units completed, a design for the lobby area and corner of the residence hall was done. The method used to complete this design was consistent with the design that proved to be the more economical option for the typical unit. The design of the lobby and corner section of the building used a similar beam spacing scheme used in the typical units. Below is a diagram showing the plan view of the atypical corner of the residence hall.

Figure 7: Atypical Floor Plan



3.6. Development of Building Cost Estimates

The cost analysis of the building was structured around the 16 CSI building divisions, so that the structural systems were broken down into their elements to help establish an organized cost. The estimate was calculated, in some instances, on a square foot means basis and others on a unit basis. The square foot estimates did not overlap with the unit basis costs, because there were very few instances where the square foot cost approach was used. The majority of the square foot cost was used to determine the electrical and mechanical costs of systems within the building. The references used to create our cost analysis were the RS MEANS publications from 2006 and 2007. In our estimate, the costs for materials and labor were calculated based on predetermined figures in the RS MEANS publications. Therefore the figures in our table reflect the overall cost of the building with the labor cost factored in to the overall cost.

A table was constructed based on the 16 CSI divisions and cost estimates were calculated for each individual division. General contracting fees and documents were all included in their own division as well as the site work for the building. The other 14 divisions actually focused on the actual cost of the building. The information provided by each division was useful in determining what amount of the total cost was subject to each division. The major divisions such as electrical and mechanical had to be calculated almost entirely from the *Square Foot Costs* book, due to the lack of working knowledge of the typical items that are required for such complicated systems. In order for us to create the most reasonable estimate we had to use the square foot approach. There were several other items that required this type of analysis as well. Items such as the fire proofing and water proofing were among a few of the other costs that were estimated on the square foot basis.

The unit cost analysis of the building required more attention to detail. Using the *Interior Cost* and the *Building Construction Cost Data* books we were able to breakdown the costs for the remaining divisions. Most items such as furniture and basic accessories could be added for the entire building so that there was a set number for each item. Based on the price of one item we generated a cost for the total items in the building to a fairly certain degree of accuracy. However, some of the quantities, such as drywall and bricks, were over estimated to allow for a waste factor, making our assessment of the building more accurate. Items such as nails and glue were not calculated directly because the costs of these materials already assumed in all of the assemblies cost data.

The final step considered was the cost of the general requirements and fees for the building. Contractor fees as well as architectural fees were an entire separate cost which, according to *2006 Square Foot Cost Means* book for a 4-7 story apartment building, would reflect about 30-32% of the overall cost. Therefore, the cost for the building was adjusted so that the cost for design and general requirements met this standard. Once this was done, the overall cost was calculated.

3.7. Development of LEED Building Cost Estimate

Alternative costs for constructing a LEED certified and a LEED silver certified building were generated. The United States Green Building Council recognizes Leadership in Energy and Environmental Design (LEED) with various levels of building certifications. There are a total of 69 available points in the new and on-campus construction category, of those 25 to 32 points are needed for certification and 33 to 38 points are needed for silver certification.

A cost estimate for the building was calculated using the 16 CSI divisions as a template. Using that template various costs were adjusted to recognize the cost of LEED requirements. The points needed to achieve certification were met through either adding a feature to the building, or changing a type of material, or modifying the way in which a given material was used in construction. This adjustment in type of material being used in the building or requirement of different features in the building altered the original construction cost estimate of the dormitory.

The original cost estimate for the dormitory was based on conventional construction methods. The cost for a LEED certified building and a LEED silver building, included costs accrued through the replacement of some of the conventional methods with more environmentally friendly or “green” construction methods.

4. Analysis

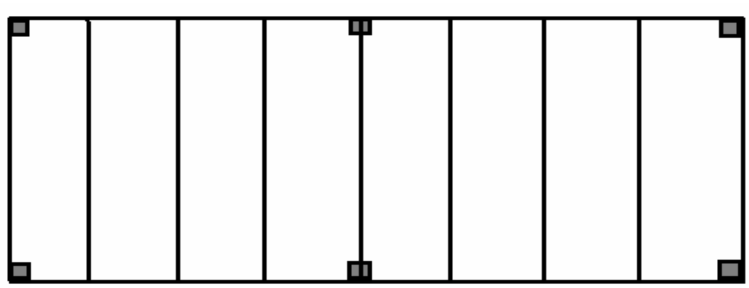
These sections include the results that were found when following the procedures set out in the methodology sections. The concrete, steel, and composite designs were done using three different column spacing layouts. For all of the options, a construction cost estimate was calculated. The more economical option was then used to design the atypical sections of the residence hall. With the structural system of the building complete, a total construction cost estimate was determined. With the recent trend with green engineering, a second cost was estimated to produce a LEED certified structure. The following sections explain the results in more detail.

4.1. Analysis of Concrete Systems

The concrete design was based on several different column spacing options for each of the typical 20’ x 40’ bay areas. Though there were many different beam and column arrangements that could have been used, only three were chosen for investigation. One of the major factors that influenced the design of the beams and columns was the desire to place all of the columns only along the exterior walls of each dwelling unit to ensure maximum usable floor space in the apartments. With this in mind, the final decision for the best possible concrete design was based on the overall cost of the three structural layouts.

The first of the three designs consisted of six columns that were spaced 20’ x 20’ over the bay area. Each of the interior columns supported a tributary area of 400 sq ft. The corner columns however were only subject to half of the tributary area that the interior columns supported. The beams and girders were also 20’ long, and the beams were spaced every 5’. This design consisted of nine beams and four girders for each unit in the building.

Figure 8: Unit Design Layout 1



20’ x 40’ Area

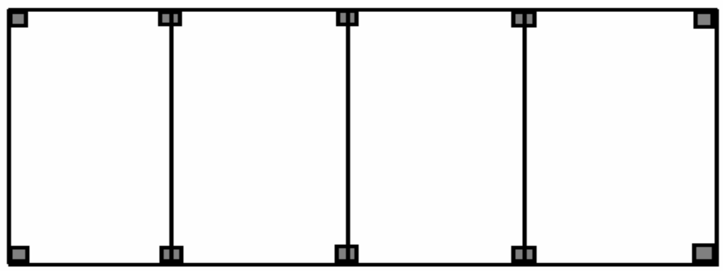
20’ Beams (9)

20’ Girders (4)

6 Columns

The second design alternative investigated the effect of reducing the column spacing to 10’ along the exterior walls of the unit. Each interior column in the layout also supported a tributary area of 200 sq ft. The beams that connected the columns were 20' long and also spaced at 10' for this scenario. Finally, eight girders were designed to be 20' long and connect all columns along the long sides of the bay. The addition of many more columns was used to help reduce the overall size of the columns and beams. Though there were many more pieces in this layout than in the first, we figured that there would be considerably less material to limit the cost. The concrete used for the analysis was a two way flat slab with a thickness of 5".

Figure 9: Unit Layout Design 2



20' x 40' Area

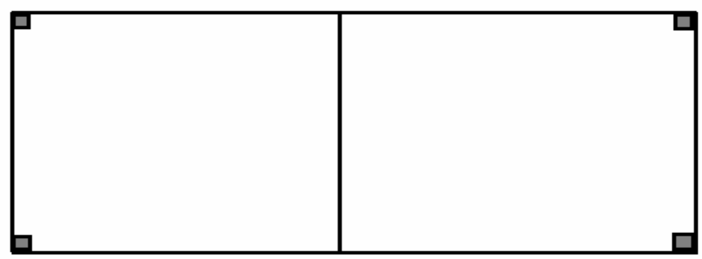
10' Girders (8)

20' Beams (5)

10 Columns

The third layout was the most extreme. It consisted of only four columns placed in each of the four corners of the 20' x 40' unit. Two girders were used to connect the columns along the long side of the bay, making them 40' in length. Finally, three beams with a length of 20' were spaced at 20' to cover the area of the bay. The members that were used in this scenario were very large in comparison to the two other alternatives.

Figure 10: Unit Layout Design 3



40’ x 20’ Area

20’ Beams (3)

40’ Girders (2)

4 Columns

2-Way Slabs supported by beams and girders

Once the designs of the slabs, beams, and columns for each of the three layouts were determined, a cost assessment was made based on the total volume of material needed to construct each of the designs. The cost estimate was made based one unit of the building which was predetermined by the group as a measure for comparing alternatives. It was decided that one unit was considered to be all four floors worth of material for the same 20’ x 40’ area of the building, or 3200 square feet of gross floor area. The size of the columns changed for each floor, so a cost assessment was made by floor for each of the three scenarios. The total cost was found based on the sum of the cost for each floor of the unit. Figures for the cost of the materials were found in the *R.S. Means Building Construction Cost Data 64th Annual Edition 2007.* The cost of steel reinforcement was given in tons of steel and that for concrete was given in cubic yards of material. Once the proper conversions were made to analyze each option, a final cost for each layout was determined.

Table 1: Volume of Material (Cubic Inches)

	Beam		Girder		Column		TOTAL	
Scenario	Concrete	Steel	Concrete	Steel	Concrete	Steel	Concrete	Steel
1	8294400	69120	7188480	55680	500035	4542	15982915	129342
2	6220800	72000	7188480	23040	833392	7569	14242672	102609
3	5391360	100800	16404480	130560	434391	3946	22230231	235306

Table 2: Cost of Concrete by Volume

	VOLUME			COST
	in3	ft3	yard	$150/yard
Layout	Concrete	Concrete	Concrete	Concrete
1	15982915	110992.5	4110.8	$616,625
2	14242672	98907.4	3663.2	$549,486
3	22230231	154376.6	5717.7	$857,648

Table 3: Cost of Steel by Weight

	VOLUME		WEIGHT		COST
	in3	ft3	490lb/ft3	Tons	$800/ton
Layout	Steel	Steel	Steel	Steel	Steel
1	129342	898.2	440122.1	220.1	$176,049
2	102609	712.6	349155.6	174.6	$139,663
3	235306	1634.1	800694	400.3	$320,278

Table 4: Total Cost by Method

COST	Concrete	Steel	Total	TOTAL
1	411083.2	176048.8	587132	$587,000
2	366323.9	139662.3	505986.2	$506,000
3	571765.2	320277.6	892042.8	$892,000

Based on the cost of the material per unit volume, the second design proved to be the best option for the concrete designs. Table 4 shows the overall cost for each situation. The second layout requires the least amount of reinforcing steel and concrete. The lowest cost for the typical areas of the building would be about $500,000 per unit or $156.00 per square foot using this second approach.

4.2. Analysis of Structural Steel Systems

The steel designs were done following the LRFD method. Three different column spacing options were investigated for a typical unit. The schemes were broken into three column spacings, and those with multiple beam spacing alternatives were sub parts. Earlier figures display the three different column spacings. These were examined to determine if multiple, relatively lightweight beams would be a more cost efficient method than a few, heavier beams.

The first column layout located a column only in the corners of one unit. This spacing is 40 feet by 20 feet. For this scheme, the girders span 40 feet and the beams span 20 feet. Design of the infill beams for this scheme involved the following spacings: 20 feet, 10 feet, and 5 feet. These options were designed for a typical roof level and a typical interior floor level. Table 5 shows the results.

Table 5: Scheme 1 Results

Scheme	Level	Girder	Spacing	Beam
1.1	Roof	W24x84	20 ft	W14x53
	Interior	W24x84	20 ft	W14x61
1.2	Roof	W24x84	10 ft	W12x40
	Interior	W24x84	10 ft	W12x40
1.3	Roof	W24x84	5 ft	W10x26
	Interior	W24x84	5 ft	W10x26

The second column layout investigated a column spacing of 20 feet, with a total of 6 columns in a unit. Using this column spacing, girders and beams span 20 feet. The beam spacings studied for this scheme are similar to those used in the previous scheme: 20 feet, 10 feet, and 5 feet. The following table summarizes the resulting beams and girders for this scheme.

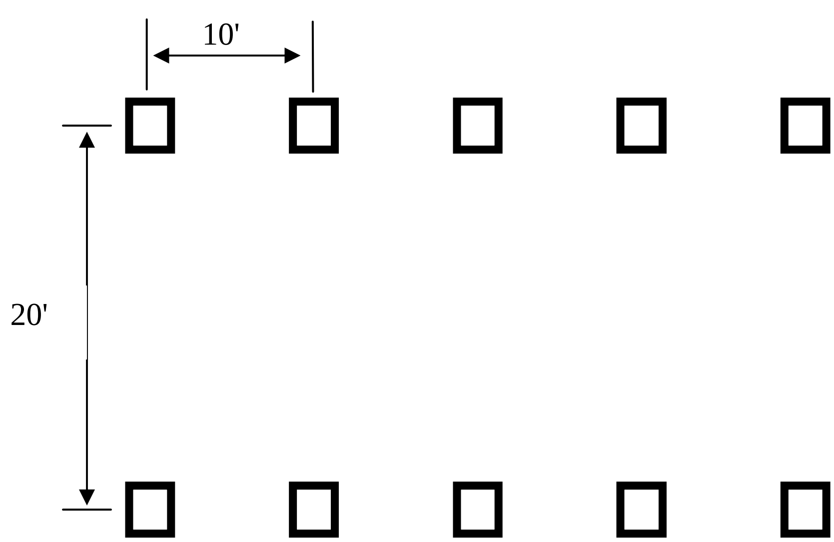
Table 6: Scheme 2 Results

Scheme	Level	Girder	Spacing	Beam
2.1	Roof	W14x48	20 ft	W14x53
	Interior	W14x48	20 ft	W14x61
2.2	Roof	W14x48	10 ft	W12x40
	Interior	W14x48	10 ft	W12x40
2.3	Roof	W14x48	5 ft	W10x26
	Interior	W14x48	5 ft	W10x26

These results show that the beam sizes in this scheme are the same as those for the first scheme. Since the loads, spans, and tributary areas are the same it would be expected to find the same shape working for both schemes. As anticipated, the girders are lighter in this scheme than the previous scheme because they span a shorter distance.

The third scheme has column spacing every 10 feet by 20 feet. This scheme has a total of 10 columns in a typical unit. Girders span 20 feet and beams span 10 feet. The following diagram displays the column spacings.

Figure 11: Column Spacing Option



With this configuration of columns, the two beam options are to have two beams span 10 feet or to also include a beam in the center of the bay. The girders span the 20 foot distance between the columns. The following table has the results for these two options.

Table 7: Scheme 3 Results

Scheme	Level	Girder	Spacing	Beam
3.1	Roof	W10x26	20 ft	W8x13
	Interior	W10x26	20 ft	W8x15
3.2	Roof	W10x26	10 ft	W6x12
	Interior	W10x26	10 ft	W6x12

With the beam and girder designs completed, the next step was to examine the columns for those schemes. The given loads were in pounds per square foot; therefore, the tributary area a column would carry determined its load. The first scheme resulted in a tributary area of 400 square feet per column. Columns in the second scheme have a tributary area of 100 square feet. The tributary area for columns in the third scheme is 100 square feet. Based on these areas, columns were designed for each level in the bay. The columns are listed in the table below starting with the top level and proceeding sequentially down towards the bottom.

Table 8: Column Design Results

400 ft^2	200 ft^2	100 ft^2
W8x18	W6x12	W6x12
W6x20	W8x18	W6x12
W8x28	W5x19	W6x16
W10x33	W6x20	W8x18

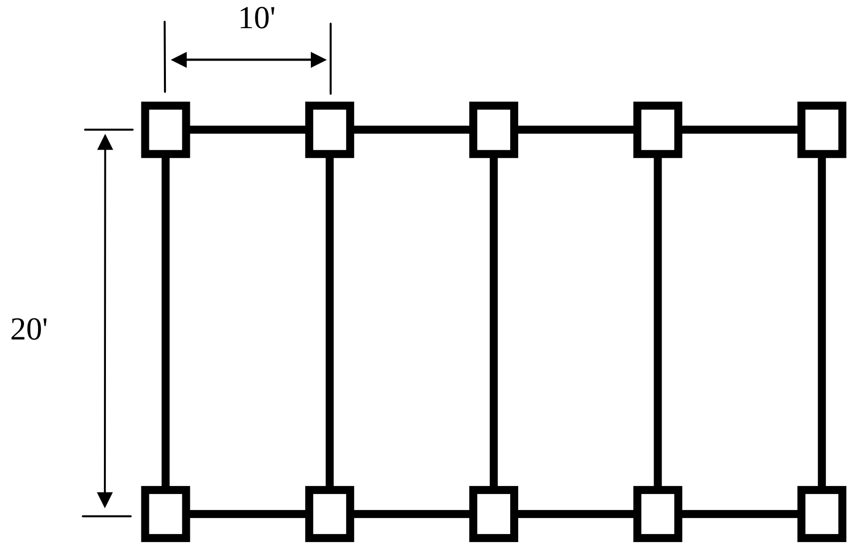
In order to determine which of the several options has the lowest cost, the marginal cost of each solution was estimated. In all of the schemes a 5-inch concrete floor slab was assumed. Given the constant slab design, the marginal cost was simply the cost of structural the steel. *R.S. Means Building Construction Cost Data 64th Annual Edition 2006* was used for estimating steel costs, and the cost data were given in dollars per linear foot of member, which includes materials, labor, and equipment costs. However, in some cases cost data for the specific members selected were not listed, and so costs were interpolated between similar sizes of the same W-shape section. The total cost of a scheme was broken into two parts, beams and columns. Tables showing the calculations of girder, beam, and column costs can be found in the appendix A. The following table summarizes the final costs by scheme.

Table 9: Structural Layout Costs

Structural Layout Scheme	Column Scheme	Total Cost
1.1	1	$58,000
1.2	1	$61,000
1.3	1	$68,000
2.1	2	$46,000
2.2	2	$49,000
2.3	2	$56,000
3.1	3	$36,000
3.2	3	$39,000

Based on the cost results, Structural Layout Scheme 3.1 resulted in the most economical solution at $36,000. It has columns spaced 10 feet by 20 feet and has beams spaced 20 feet. This scheme has concrete on metal decking spanning the 10 feet between girders. Its layout is in the figure below.

Figure 12: 10 ft Beam Spacing



4.3 Analysis of Composite Steel and Concrete Systems

Each beam and girder was sized based on LRFD and AISC design criteria, and two loading conditions were considered, depending on the location of the particular beam. One condition was used for the sizing of members in the roof, which were subject to a dead load that was of different magnitude than that of the second condition which was applied to a typical floor member. In addition the roof was not subject to any live loads though it did have to be designed for snow load, which the members of the interior floors would not be subject to. Thus the roof was designed to one condition of live loads where the interior floors were designed to another condition of live loads. The same design criteria and loading conditions were applied throughout each design scheme or arrangement of beam and girder layouts.

Slab thickness was an important issue that became a limiting factor in the design of the composite section. A span to thickness ratio of L/24, where L is equal to the largest spacing between beams, was used to determine slab thickness for the different design schemes. Three inches was added to each slab thickness to account for the corrugated decking, which is three inches deep, used to form the concrete. Based on the slab thickness criteria, the 40x20 spacing scheme was eliminated with a total slab thickness of 15 inches. The 20x20 spacing scheme resulted in an ultimate slab thickness of 9 inches. These design schemes were eliminated based on their slab thickness requirements.

Generally, the largest slab that will allow use of the flexure strength tables in the composite section of the *AISC Steel Construction Manual* is seven inches. This is based on the calculated Y2 distance, which is the distance from the center of gravity of the concrete flange force to the top flange of the beam. When this value exceeded seven inches, as it did once the slab was greater then seven inches thick, the *AISC Steel Construction Manual* no longer provided flexural strength values. Both of the schemes mentioned above, exceed the slab thicknesses for which the table provides data.

The remaining schemes resulted in an ultimate slab thickness of 7 inches or less. To maintain the rigidity of the floor, in addition to complying with reinforcement cover requirements, a standard slab thickness of 6 inches was used for all remaining design schemes calling for less than six inches of floor slab. This also helped ensure acceptable floor deflections where a scheme called for a slab thickness less than six inches. The slab thicknesses are outlined in table 10 below.

Table 10: Scheme to Slab Relationship

Scheme	Layout	Slab Thickness
1	40x20	15 inches
2	20x20	9 inches
3	20x10	7 inches
4	20x5	6 inches
5	10x10	6 inches
6	10x5	6 inches

Schemes one and two were eliminated based on slab requirements and manual limitations. Analysis continued on the remaining schemes, beginning with scheme three and following through scheme six, staying consistent with the LRFD method. A typical interior beam was analyzed followed by a floor girder in scheme three. As scheme three has the largest span and also the largest spacing of the remaining schemes, resulting in the largest tributary width, it carried the largest magnitude of dead and live loads. The design moment for this scheme is 72.3 ft-kips. The moment capacity of a W10x12 composite beam is 140 ft-kips, almost twice as much as required. The W10x12 composite beam is the smallest beam for which there are design values in the *AISC Steel Construction Manual*.

Scheme three generates the largest magnitude of forces on a typical beam and girder. As analysis continued on schemes four through six it became clear that the magnitude of the forces on typical beams and girders decreased as the spans and spacing were reduced. W10x12 composite beams were used for schemes three through six as the design capacity of the composite beam was much higher than any of the calculated capacities from gravity loads generated in the structure.

Each of the remaining design schemes all required use of the same size member for both floor beams and girders. Determination of the most effective design was reduced to identifying the scheme with the lowest cost. The design with the lowest amount of linear footage of steel will be the most effective design within the composite section of the design analysis. Based on Mean costs data, the price of steel for a W10x12 beam is $22.50 per foot and the cost of concrete at $150/cy. Table 11 outlines the amount of steel and concrete required for each scheme and a corresponding total cost for that scheme.

Table 11: Scheme Costs

Scheme	Layout	Slab Thickness	Vol. of Concrete	Cost of concrete	Amount of Steel	Cost of steel	Total cost
1	40x20	15 inches	scheme not used	scheme not used	scheme not used	scheme not used	scheme not used
2	20x20	9 inches	scheme not used	scheme not used	scheme not used	scheme not used	scheme not used
3	20x10	7 inches	70 c.y.	$10,500.00	720 lf	$16,200.00	$26,700.00
4	20x5	6 inches	60 c.y.	$9,000.00	1040 lf	$23,400.00	$32,400.00
5	10x10	6 inches	60 c.y.	$9,000.00	880 lf	$19,800.00	$28,800.00
6	10x5	6 inches	60 c.y.	$9,000.00	1200 lf	$27,000.00	$36,000.00

Based on the conditions outlined and cost of materials, the most effective composite construction design would be the 20x10 design scheme. Although this scheme has a slightly thicker floor slab resulting in a slightly higher cost of concrete the total cost for a single unit under that scheme is still the lowest at a cost of $ 26,700.00. This value does not take into account the cost of labor and equipment. In addition, the associated costs of the columns are not reflected in the construction costs outlined in the above table.

4.4 Analysis of Lateral Load-resisting Systems

The selected structural system was the steel design. The member sizes and column sizes were entered into RISA-2D Educational Version to determine sway and member stresses. The allowable sway was less than H/500, where H is the height of the level. For the 48 ft building the top floor maximum sway is 1.152 inches.

The first model did not meet the required sway, and revisions had to be made. Originally a different column size was used on each floor. The revised model had the same column size for the bottom two and another size for the top two columns. With these changes, the resulting sway at the top floor was 1.15 inches. This is just below the maximum allowed, but the serviceability of the building would not be constantly subjected to such strong winds.

4.5 Analysis of Atypical Areas

The designs for the lobby and corner section of the building were completed using steel design. Since steel design was discovered to be the more cost efficient method and the pattern of beams and girders was multiple, relatively light members, a similar style was used to design the corner section of the building.

The design was broken down into four typical members by length and tributary width. The longest girder spans 26 feet and has a tributary width of 13 feet. The longest beam spans 26 feet and has a tributary width of 6 ½ feet. The design of these members and the others was done using the same spreadsheets used in the typical unit design. The following table displays the results found.

Table 12: Atypical Design Results

Roof Level	Member	Length	Tributary Width	W-Shape
	A	26	6.5	W18x35
	B	26	13	W21x44
	C	20	5	W12x22
	D	20	10	W16x26
Interior Floors	Member	Length	Tributary Width	W-Shape
	A	26	6.5	W18x40
	B	26	13	W24x55
	C	20	5	W14x26
	D	20	10	W18x35

A cost was then determined for the atypical area. This followed the same method used in the steel design section, costs per linear foot were found in *RS Means Building Construction Cost Data*. The total construction cost estimate for the steel in the atypical area was $106,000. This will be added to the total estimate of the building.

4.6 Analysis of Building Cost Estimates

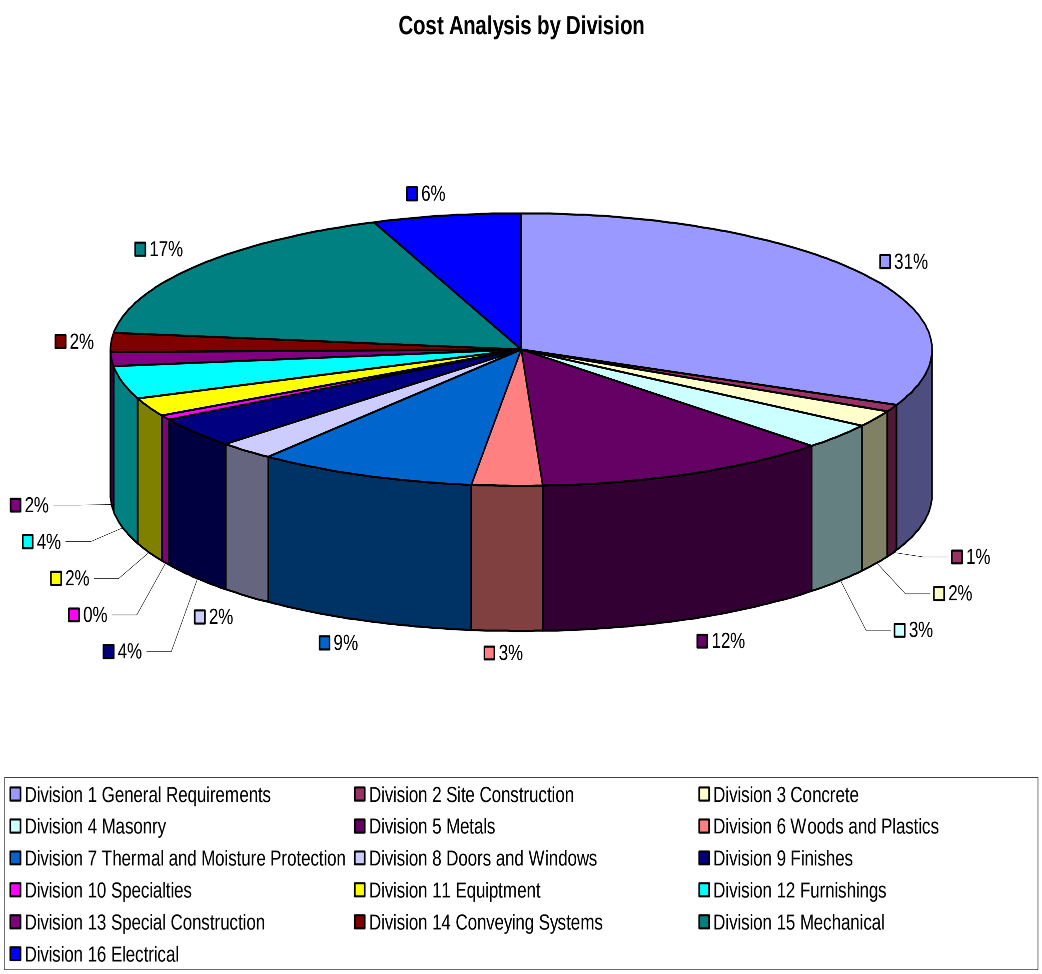
The overall cost of the building was based on the sum of the prices obtained for each of the 16 CSI divisions. The total cost was estimate to be just below $7,400,000 for the entire project. This number represents the cost to build the project; it does not represent the operating costs over time. Items such as electricity, heating, water, waste disposal, and internet are not factored into the cost of the build. A breakdown of the costs of each division as well as the percent of the cost for each division was made to show where the money was being spent. Here is the breakdown for the cost of each division.

Table 13: Overall Cost Analysis

DIVISION	COST	%
Division 1 General Requirements	2326452	31.54
Division 2 Site Construction	66239.7	0.90
Division 3 Concrete	157713.1	2.14
Division 4 Masonry	220907.5	2.99
Division 5 Metals	860112	11.66
Division 6 Woods and Plastics	194432	2.64
Division 7 Thermal and Moisture Protection	640814.6	8.69
Division 8 Doors and Windows	159002.2	2.16
Division 9 Finishes	279738.6	3.79
Division 10 Specialties	23572	0.32
Division 11 Equipment	175778	2.38
Division 12 Furnishings	278356.8	3.77
Division 13 Special Construction	132795.4	1.80
Division 14 Conveying Systems	159900	2.17
Division 15 Mechanical	1262597	17.12
Division 16 Electrical	437752.7	5.93
TOTAL COST ($)	$7,376,164	100.00

The following chart is a visual breakdown of how the money for the project would be spent. The numbers for this chart are based on the percent of overall cost for each division from Table 13. The overall cost of the building is $140 per square foot. Our square foot cost is higher than the RS Means building cost of $125 per square foot.

Figure 13: Cost Breakdown by Division



4.7 Analysis of LEED Building Cost Estimate

LEED certification and LEED silver certification was achieved through minimal adjustments to the current expected construction techniques and materials. As stated in previous sections LEED certification requires a minimum of 25 points and silver certification requires a minimum of 33 points. An original construction cost estimate was developed using 16 CSI divisions and that estimate was adjusted to reflect LEED construction requirements.

Very little investment was required in order to reach the minimum of 25 points required for LEED certification. Although those 25 points may be considered "low hanging fruit" they are an improvement in terms of environmental consideration. Many of the available points that were obtained required no addition investment. LEED certification can be reached simply by adding an additional $12,000 in material cost to the original construction cost of the building. It is important to note that the $12,000 additional construction cost does not include the cost of construction and labor.

LEED silver certification can be achieved with a more considerable investment. The 33 points required for silver certification would require an initial investment of $225,634. This cost is in addition to the original construction cost outlined above. Bringing the total additional original construction cost to $237.634. It is also important to note that again, this cost does not include the cost of labor and construction. The following table outlines the options used to obtain 33 points.

Table 13: LEED Silver Certification Options

LEED	***POINTS***
Bike Racks for 16 people	1
reducing heat island effect	1
reflective roof top	1
water use reduction by 30%	2
energy reduction 25%	3
10% renewable energy	2
ozone protection	1
CO2 detectors	1
low emmiting adhesives and sealants	1
paint and coatings	1
low emmiting carpet	1
motion detectors and operable windows	1
site selection	1
development density	1
alternative transportation	1
restoring open space	1
make sure that project manager is LEED accredited	1
recycling 75% of waste during construction	2
developing an indoor air quality flushing	1
5 carpool parking spaces	1
efficient angling of lights onto property	1
no irrigation system	2
reuse 5% building materials	1
using 10% recycled materials	2
certified wood	1
20% materials must come from within 500 miles	1
SILVER ACCREDITED TOTAL POINTS	33

Appendix C outlines in detail the options that were utilized to achieve the minimum of 33 points required for silver certification and the costs associated with those changes. The changes in building techniques and materials that were required to reach the 33 point minimum for silver certification affected only five primary CSI divisions. The divisions that were affected include: site construction, Equipment, Special Construction, Mechanical, and Electrical.

Generally the additional investment required to achieve LEED certification, even on a bare bones scale, is minimal considering the entire initial construction cost for the building. However, achieving a higher certification standard would require some innovative design techniques and a true dedication to "green" design from the ground up. With some thoughtful and planned LEED construction practices put into place from the outset of a project, LEED certification is an easy goal to obtain in almost any project setting.

5 Conclusion

The goal of this project was to meet the needs expressed by WPI to encourage more upperclassmen students to live on-campus. They would provide a much needed leadership role that is currently lacking. A proposed solution was to design a new apartment style residence hall. This residence hall can house 96 students in 24 apartments. Each student would receive their own bedroom and in each apartment there is a kitchen, bathroom, and living room. Each apartment consists of two floors and the residence hall stacks two apartments on top of each other for a total height of four floors. The scope of the project was to design the building using the most economical structural system, determine an estimated construction cost, and introduce a second option for a LEED certified residence hall.

The design of the project began by comparing concrete, steel, and a composite of the two materials. A typical stack of two apartments was designed and a cost was associated with all of the different options. Based on those findings, the steel structural system was selected and used to design the remainder of the building. Some key design attributes include a building height of 48 feet and total livable area of 52,600 square feet. Amenities in the building include a laundry room, study rooms, entertainment rooms, and computer labs.

Using the steel structural system, a cost estimate of the project was determined. The cost was estimated using RS Means in the 16 CSI divisions, and determined to be \$7.2 M. The square foot cost of the building was calculated to be \$138. This is a reasonable value considering RS Means overall building estimates for dorms are

$125/sqft. The expected cost increase for this project is because the RS Means value is for a standard dormitory, which differs from the apartment style design.

LEED design options were also considered for the construction of the dormitory. The effect of constructing the building to LEED Silver Certification increase the original building cost by $250,000. This would result in only a marginal cost per square foot increase.

The goal of the project was to design a building that met the appeal of upperclassmen, while being cost efficient. Work is underway to construct a new residence hall for an estimated 250 students. As a comparison, this $33 M project has a $132,000 per student original construction cost. The proposed 96 person residence hall has a $75,000 per student original construction cost. Though it is less than half the size, it is a more economical solution based on per student costs. Overall, this project is a step in the right direction towards solving the issue that centers around the lack of upperclassmen presence in on-campus housing.

I. Appendix

A. Proposal

Worcester Polytechnic Institute has a desire to return upperclassmen back on campus, but do not have the necessary housing requirements. Residential Services believes that the seniors and juniors could provide valuable leadership skills and be role models for the freshman and sophomores students. Currently, the majority of upper-class students live in off campus apartments in the nearby neighborhoods of Worcester. The opportunity of upperclassmen to live on campus is small. Often students can find more desirable housing in the off campus apartments such as their own bedrooms and at a more affordable rate. The Greek system also houses a significant number of upper-class students. Worcester Polytechnic Institute is now making a serious effort to bring upperclassmen back on campus. To assist in this issue, a new upper-class residence hall is needed. The focus of this Major Qualifying Project is to design this new residence hall that will be appealing to upper-class students.

The first issue when designing a new resident hall is its location. Worcester Polytechnic Institute has a desire to use currently owned property and not have to acquire new land. Worcester Polytechnic Institute obtained a new piece of land on 23 Trowbridge Road at the end of 2003. This piece of land was a grant given by Mr. Ersckin. The lot is between Trowbridge Road and Einhorn Street and is about 50,000 square feet. The shape of the lot and its size will influence the design of the building.

In an effort to fill Worcester Polytechnic Institute's need for a new residence hall and the availability of 23 Trowbridge, as the potential location for a future dormitory, this Major Qualifying Project will design a building for this lot.

B. Structural System Design

Table 14: Roof Columns

Roof Column Loads

	1 & 2		3	
Snow Load	35	psf	35	psf
DL				
waterproofing	5	psf	10	psf
concrete	150	pcf	150	pcf
	5	in	5	in
	62.5	psf	62.5	psf
suspended ceiling	2	psf	2	psf
Total DL	69.5	psf	74.5	psf
Column Trib. Area	200	sf	400	sf
P_u	139.4	psf	145.4	psf
P_u	27.88	kips	58.16	kips
e	3	in	3	in
M_{top}	6.97	ft-kips	14.54	ft-kips
e	2	in	2	in
M_{bot}	4.65	ft-kips	9.69	ft-kips
f'c	3000	psi	3000	psi
Fy	50000	psi	50000	psi
Pt	0.02		0.02	
Ag(trial)	16.52	in2	34.47	in2
$A_{assumed}$	100	in2	144	in2
k	1		1	
Lu	12	feet	12	feet
h	10	in	12	in
r	3	in	3.6	in
Slenderness Test	Slender		Slender	
min e	0.9	in	0.96	in
Ec	3122018.58	psi	3122018.58	psi
h	10	in	12	in
b	10	in	12	in
Ig	833.33	in4	1728	in4
Bd	0.60		0.61	
EI	651121170	in2/lb	1336304794	in2/lb
Cm	0.87		0.87	
Pc	309.91		636.03	
d_{ns}	0.98		0.99	

check	OK		OK		
Mc	6.86	ft-kips		14.35	ft-kips

Table 15: 3rd Floor Columns

LL	75	psf	75	psf
DL	16	psf	16	psf
MEP	10	psf	10	psf
concrete	150	pcf	150	pcf
	10	in	10	in
	125	psf	125	psf
suspended ceiling	4	psf	4	psf
Total DL	155	psf	155	psf
Column Trib. Area	200	sf	400	sf
P_u	306	psf	306	psf
P_u	61.2	kips	122.4	kips
e	3	in	3	in
M_{top}	15.3	ft-kips	30.6	ft-kips
e	2	in	2	in
M_{bot}	10.2	ft-kips	20.4	ft-kips
f'c	3000	psi	3000	psi
Fy	50000	psi	50000	psi
Pt	0.02		0.02	
Ag(trial)	36.27	in2	72.53	in2
$A_{assumed}$	144	in2	196	in2
k	1		1	
Lu	12	feet	12	feet
h	12	in	14	in
r	3.6	in	4.2	in
Slenderness Test	Slender		Slender	
min e	0.96	in	1.02	in
Ec	3122018.58	psi	3122018.578	psi
h	12	in	15	in
b	12	in	14	in
Ig	1728	in4	3201.33	in4
Bd	0.61		0.61	
EI	1342132943	in2/lb	2486466971	in2/lb
Cm	0.87		0.87	
Pc	638.81		1183.47	
d_{ns}	0.99		1.01	
check	OK		OK	
Mc	15.20	ft-kips	30.76	ft-kips

Table 16: 2nd Floor Columns

LL	115	psf	115	psf
DL	24	psf	24	psf
MEP	15	psf	15	psf
concrete	150	pcf	150	pcf
	15	in	15	in
	187.5	psf	187.5	psf
suspended ceiling	6	psf	6	psf
Total DL	232.5	psf	232.5	psf
Column Trib. Area	200	sf	400	sf
P_u	463	psf	463	psf
P_u	92.6	kips	185.2	kips
e	3	in	3	in
M_{top}	23.15	ft-kips	46.3	ft-kips
e	2	in	2	in
M_{bot}	15.43	ft-kips	30.87	ft-kips
f'c	3000	psi	3000	psi
Fy	50000	psi	50000	psi
Pt	0.015		0.015	
Ag(trial)	54.87	in2	109.75	in2
$A_{assumed}$	144	in2	196	in2
k	1		1	
Lu	12	feet	12	feet
h	12	in	14	in
r	3.6	in	4.2	in
Slenderness Test	Slender		Slender	
min e	0.96	in	1.02	in
Ec	3122019	psi	3122019	psi
h	14	in	16	in
b	14	in	16	in
Ig	3201.333	in4	5461.333	in4
Bd	0.60		0.60	
EI	2.49E+09	in2/lb	4.26E+09	in2/lb
Cm	0.87		0.87	
Pc	1187.35		2025.56	
d_{ns}	0.97		0.99	
check	OK		OK	
Mc	22.39	ft-kips	45.70	ft-kips

Table 17: 1st Floor Columns

LL	155	psf	155	psf
DL	32	psf	32	psf
MEP	20	psf	20	psf
concrete	150	pcf	150	pcf
	20	in	20	in
	250	psf	250	psf
suspended ceiling	8	psf	8	psf
Total DL	310	psf	310	psf
Column Trib. Area	200	sf	400	sf
P_u	620	psf	620	psf
P_u	124	kips	248	kips
e	3	in	3	in
M_{top}	31	ft-kips	62	ft-kips
e	2	in	2	in
M_{bot}	20.67	ft-kips	41.33	ft-kips
f'c	3000	psi	3000	psi
Fy	50000	psi	50000	psi
Pt	0.02		0.02	
Ag(trial)	73.48	in2	146.96	in2
$A_{assumed}$	196	in2	196	in2
k	1		1	
Lu	12	feet	12	feet
h	14	in	14	in
r	4.2	in	4.2	in
Slenderness Test	Slender		Slender	
min e	1.02	in	1.02	in
Ec	3122018.58	psi	3122018.6	psi
h	16	in	17	in
b	16	in	17	in
Ig	5461.33	in4	6960.0833	in4
Bd	0.6		0.6	
EI	4262596032	in2/lb	5.432E+09	in2/lb
Cm	0.87		0.87	
Pc	2028.85		2585.62	
d_{ns}	0.94		0.99	
check	OK		OK	
Mc	29.25	ft-kips	61.61	ft-kips

Table 18: Girder Loads

	Girder Loading	Roof	
LL		35	psf
DL		69.5	
	waterproofing	5	psf
	concrete	150	lb/cuft
	concrete thickness	5	in
	suspended ceiling	2	psf
Total Load		139.4	psf
	tributary width	10	ft
	length	40	ft
Moment		278.8	ft kips

	Girder Loading	Interior	
LL		40	psf
DL		77.5	
	MEP	5	psf
	concrete	150	lb/cuft
	concrete thickness	5	in
	suspended ceiling	2	psf
	steel partitions	4	psf
	Flooring	4	psf
Total Load		157	psf
	tributary width	10	ft
	length	40	ft
Moment		314	ft kips

Table 19: Beam Loads

	Beam Loading	Roof	
LL		35	psf
DL		69.5	
	waterproofing	5	psf
	concrete	150	lb/cuft
	concrete thickness	5	in
	suspended ceiling	2	psf
Total Load		139.4	psf
	tributary width	20	ft
	length	20	ft
Moment		139.4	ft kips

	Beam Loading	Interior	
LL		40	psf
DL		77.5	
	MEP	5	psf
	concrete	150	lb/cuft
	concrete thickness	5	in
	suspended ceiling	2	psf
	steel partitions	4	psf
	Flooring	4	psf
Total Load		157	psf
	tributary width	20	ft
	length	20	ft
Moment		157	ft kips

Table 20: Girder Design

Girders		
Positive	**1**	
Span Width	20	ft
b	5	ft
h	18	in
As	1.5	in2
Fy	50000	psi
f'c	3000	psi
d	14.5	in
dt	15.75	in
a	0.49	in
As min	0.57	in2
As min	0.70	in2
bw	12	in
s	0.9	
sMn	80.18	kips
Negative	**1**	
b	12	in
d	15.5	in
dt	15.75	in
a	3.47	in
As	2.125	in2
As min	0.61	in2
As min	0.74	in2
a/dt	0.22	
.375b	0.32	
s	0.9	
sMn	81.79	kips

Girders		
Positive	**2**	
Span Width	20	ft
b	5	ft
h	18	in
As	0.75	in2
Fy	50000	psi
f'c	3000	psi
d	14.5	in
dt	15.75	in
a	0.25	in
As min	0.57	in2
As min	0.70	in2
bw	12	in
s	0.9	
sMn	40.44	kips
Negative	**2**	
b	12	in
d	15.5	in
dt	15.75	in
a	1.23	in
As	0.75	in2
As min	0.61	in2
As min	0.74	in2
a/dt	0.08	
.375b	0.32	
s	0.90	
sMn	32.03	kips

Girders		
Positive	**3**	
Span Width	20	ft
b	5	ft
h	36	in
As	2.75	in2
Fy	50000	psi
f'c	3000	psi
d	32.50	in
dt	33.75	in
a	0.90	in
As min	1.92	in2
As min	2.34	in2
bw	18.00	in
s	0.90	
sMn	330.52	kips
Negative	**3**	
b	18	in
d	33.5	in
dt	33.75	in
a	6.26	in
As	5.75	in2
As min	1.98	in2
As min	2.41	in2
a/dt	0.19	
.375b	0.32	
s	0.90	
sMn	320.60	kips

Table 21: Beam Design

Beams		
Positive	**1**	
Span Width	5	ft
b	1.25	ft
h	18	in
As	1	in2
Fy	50000	psi
f'c	3000	psi
d	14.5	in
dt	15.75	in
a	1.31	in
As min	0.57	in2
As min	0.70	in2
bw	12	in
s	0.9	
sMn	51.92	kips
Negative	**1**	
b	12	ft
d	15.5	in
dt	15.75	in
a	1.63	in
As	1	in2
As min	0.61	in2
As min	0.74	in2
a/dt	0.10	
.375b	0.32	
s	0.9	
sMn	41.94	kips

Beams		
Positive	**2**	
Span Width	10	ft
b	2.5	ft
h	18	in
As	1.5	in2
Fy	50000	psi
f'c	3000	psi
d	14.5	in
dt	15.75	in
a	0.98	in
As min	0.57	in2
As min	0.70	in2
bw	12.00	in
s	0.90	
sMn	78.81	kips
Negative	**2**	
b	12	ft
d	15.5	in
dt	15.75	in
a	3.68	in
As	2.25	in2
As min	0.61	in2
As min	0.74	in2
a/dt	0.23	
.375b	0.32	
s	0.90	
sMn	85.74	kips

Beams		
Positive	**3**	
Span Width	20	ft
b	5	ft
h	18	in
As	3	in2
Fy	50000	psi
f'c	3000	psi
d	14.5	in
dt	15.75	in
a	0.98	in
As min	0.57	in2
As min	0.70	in2
bw	12.00	in
s	0.90	
sMn	157.61	kips
Negative	**3**	
b	12	ft
d	15.5	in
dt	15.75	in
a	9.40	in
As	5.75	in2
As min	0.61	in2
As min	0.74	in2
a/dt	0.60	
.375b	0.32	
s	0.90	
sMn	157.46	kips

Table 22: Beam Design Volumes (Cu. Inch)

1		BEAMS				
Floor	#	Length (in)	X Area (in2)	Volume	As (in2)	Vol As
Top	9	240	240	57600	2.00	480
3rd	9	240	240	57600	2.00	480
2nd	9	240	240	57600	2.00	480
1st	9	240	240	57600	2.00	480
TOTAL	36			230400		1920
				8294400		69120

2		BEAMS				
Floor	#	Length (in)	X Area (in2)	Volume	As (in2)	Vol As
Top	5	240	324	77760	3.75	900
3rd	5	240	324	77760	3.75	900
2nd	5	240	324	77760	3.75	900
1st	5	240	324	77760	3.75	900
TOTAL	20			311040		3600
				6220800		72000

3		BEAMS				
Floor	#	Length (in)	X Area (in2)	Volume	As (in2)	Vol As
Top	3	240	468	112320	8.75	2100
3rd	3	240	468	112320	8.75	2100
2nd	3	240	468	112320	8.75	2100
1st	3	240	468	112320	8.75	2100
TOTAL	12			449280		8400
				5391360		100800

Table 23: Girder Design Volumes (Cu. Inch)

1	GIRDERS					
Floor	#	Length	X Area	Volume	As	Vol As
Top	4	240	468	112320	3.63	870
3rd	4	240	468	112320	3.63	870
2nd	4	240	468	112320	3.63	870
1st	4	240	468	112320	3.63	870
TOTAL	16			449280		3480
				7188480		55680

2	GIRDERS					
Floor	#	Length	X Area	Volume	As	Vol As
Top	8	120	468	56160	1.50	180
3rd	8	120	468	56160	1.50	180
2nd	8	120	468	56160	1.50	180
1st	8	120	468	56160	1.50	180
TOTAL	32			224640		720
				7188480		23040

3	GIRDERS					
Floor	#	Length	X Area	Volume	As	Vol As
Top	2	480	1068	512640	8.50	4080
3rd	2	480	1068	512640	8.50	4080
2nd	2	480	1068	512640	8.50	4080
1st	2	480	1068	512640	8.50	4080
TOTAL	8			2050560		16320
				16404480		130560

Table 24: Column Design Volumes (Cu. Inch)

1		Columns						Concrete		Steel	
FLOORS	#	Length (in)	X Area (in2)	Volume	As (in2)	Vol As	Area	Vol	Total Vol	Vol	Total Vol
Top	6	144	100	14400	0.9	129.60	99.10	14270	85622	130	778
3rd	6	144	144	20736	1.30	186.62	142.70	20549	123296	187	1120
2nd	6	144	144	20736	1.30	186.62	142.70	20549	123296	187	1120
1st	6	144	196	28224	1.76	254.02	194.24	27970	167820	254	1524
						TOTAL			500035		4541

2		Columns						Concrete		Steel	
FLOORS	#	Length (in)	X Area (in2)	Volume	As (in2)	Vol As	Area	Vol	Total Vol	Vol	Total Vol
Top	10	144	100	14400	0.90	129.60	99.10	14270	142704	130	1296
3rd	10	144	144	20736	1.30	186.62	142.70	20549	205494	187	1866
2nd	10	144	144	20736	1.30	186.62	142.70	20549	205494	187	1866
1st	10	144	196	28224	1.76	254.02	194.24	27970	279700	254	2540
						TOTAL			833391		7569

3		Columns						Concrete		Steel	
FLOORS	#	Length (in)	X Area (in2)	Volume	As (in2)	Vol As	Area	Vol	Total Vol	Vol	Total Vol
Top	4	144	144	20736	1.30	186.62	143	20549	82198	187	746
3rd	4	144	196	28224	1.76	254.02	194	27970	111880	254	1016
2nd	4	144	196	28224	1.76	254.02	194	27970	111880	254	1016
1st	4	144	225	32400	2.03	291.60	223	32108	128434	292	1166
						TOTAL			434391		3945

Table 25: Steel Interior Beam Design

	20 ft beam				10 ft beam	
	5 ft beam spacing		10 ft beam spacing	20 ft beam spacing	5 ft beam spacing	10 ft beam spacing
Live Loads	40 psf	40 psf	40 psf	40 psf	40 psf	40 psf
DL						
Hardwood flooring	4 psf	4 psf	4 psf	4 psf	4 psf	4 psf
Movable steel partitions	4 psf	4 psf	4 psf	4 psf	4 psf	4 psf
MEP	5 psf	5 psf	5 psf	5 psf	5 psf	5 psf
suspended ceiling	2 psf	2 psf	2 psf	2 psf	2 psf	2 psf
concrete	150 pcf	150 pcf	150 pcf	150 pcf	150 pcf	150 pcf
	5 in	5 in	5 in	5 in	5 in	5 in
	62.5 psf	62.5 psf	62.5 psf	62.5 psf	62.5 psf	62.5 psf
Total DL	68.5 psf	68.5 psf	68.5 psf	68.5 psf	68.5 psf	68.5 psf
Tributary Width	5 ft	5 ft	10 ft	20 ft	5 ft	10 ft
Beam Length	20 ft	20 ft	20 ft	20 ft	10 ft	10 ft
Fy	50 ksi	50 ksi	50 ksi	50 ksi	50 ksi	50 ksi
C_1	161	161	161	161	161	161
w_u	731 plf	731 plf	1462 plf	2924 plf	731 plf	1462 plf
M_u	36.55 ft-kips	36.55 ft-kips	73.1 ft-kips	146.2 ft-kips	9.1375 ft-kips	18.275 ft-kips
Z_{reqd}	9.75 in^3	9.75 in^3	19.49 in^3	38.99 in^3	2.44 in^3	4.87 in^3
	W10x19	W10x26	W12x40	**W14x61**	W6x12	W8x15
depth	10 in	10 in	12 in	14 in	6 in	8 in
weight	19 plf	26 plf	40 plf	61 plf	12 plf	15 plf
Z_x	21.6 in^3	31.3 in^3	57 in^3	102 in^3	8.3 in^3	13.6 in^3
I_x	96.3 in^4	144 in^4	307 in^4	640 in^4	22.1 in^4	48 in^4
W_u	753.8 plf	762.2 plf	1510 plf	2997.2 plf	745.4 plf	1480 plf
M_u	37.69 ft-kips	38.11 ft-kips	75.5 ft-kips	149.86 ft-kips	9.3175 ft-kips	18.5 ft-kips
Z_{reqd}	10.05 in^3	10.16 in^3	20.13 in^3	39.96 in^3	2.48 in^3	4.93 in^3
$Z_{reqd} < Z_{actual}$	OK	OK	OK	OK	OK	OK
Δ	0.97 in	0.66 in	0.61 in	0.58 in	0.26 in	0.24 in
Δ_{max}	0.67 in	0.67 in	0.67 in	0.67 in	0.33 in	0.33 in
$\Delta < \Delta_{max}$	NO	OK	OK	OK	OK	OK
Floor Depth	15.00 in	15.00 in	17.00 in	19.00 in	11.00 in	13.00 in
Depth < 3ft	OK	OK	OK	OK	OK	OK
Checks	FALSE	OK	OK	OK	OK	OK

Table 26: Steel Roof Beam Design

	20 ft beam					10 ft beam		
	5 ft beam spacing					5 ft beam spacing		
Snow	35 psf	35 psf	35 psf	35 psf	35 psf	35 psf	35 psf	35 psf
DL								
waterproofing	5 psf	5 psf	5 psf	5 psf	5 psf	5 psf	5 psf	5 psf
concrete	150 pcf	150 pcf	150 pcf	150 pcf	150 pcf	150 pcf	150 pcf	150 pcf
	5 in	5 in	5 in	5 in	5 in	5 in	5 in	5 in
	62.5 psf	62.5 psf	62.5 psf	62.5 psf	62.5 psf	62.5 psf	62.5 psf	62.5 psf
suspended ceiling	2 psf	2 psf	2 psf	2 psf	2 psf	2 psf	2 psf	2 psf
Total DL	69.5 psf	69.5 psf	69.5 psf	69.5 psf	69.5 psf	69.5 psf	69.5 psf	69.5 psf
Tributary Width	5 ft	5 ft	10 ft	10 ft	20 ft	5 ft	5 ft	10 ft
Beam Length	20 ft	20 ft	20 ft	20 ft	20 ft	10 ft	10 ft	10 ft
Fy	50 ksi	50 ksi	50 ksi	50 ksi	50 ksi	50 ksi	50 ksi	50 ksi
C_1	161	161	161	161	161	161	161	161
w_u	697 plf	697 plf	1394 plf	1394 plf	2788 plf	697 plf	697 plf	1394 plf
M_u	34.85 ft-kips	34.85 ft-kips	69.7 ft-kips	69.7 ft-kips	139.4 ft-kips	8.7125 ft-kips	8.7125 ft-kips	17.425 ft-kips
Z_{reqd}	9.29 in^3	9.29 in^3	18.59 in^3	18.59 in^3	37.17 in^3	2.32 in^3	2.32 in^3	4.65 in^3
	W10x26	**W14x48**	**W12x40**	**W14x48**	**W14x53**	W8x13	**W6x12**	**W8x13**
depth	10 in	14 in	12 in	14 in	14 in	8 in	6 in	8 in
weight	26 plf	48 plf	40 plf	48 plf	53 plf	13 plf	12 plf	13 plf
Z_x	31.3 in^3	78.4 in^3	57 in^3	78.4 in^3	87.1 in^3	11.4 in^3	9.3 in^3	11.4 in^3
I_x	144 in^4	484 in^4	307 in^4	484 in^4	541 in^4	39.6 in^4	22.1 in^4	39.6 in^4
W_u	728.2 plf	754.6 plf	1442 plf	1452 plf	2852 plf	712.6 plf	711.4 plf	1409.6 plf
M_u	36.41 ft-kips	37.73 ft-kips	72.1 ft-kips	72.58 ft-kips	142.6 ft-kips	8.9075 ft-kips	8.8925 ft-kips	17.62 ft-kips
Z_{reqd}	9.71 in^3	10.06 in^3	19.23 in^3	19.35 in^3	38.02 in^3	2.38 in^3	2.37 in^3	4.70 in^3
$Z_{reqd} < Z_{actual}$	OK	OK	OK	OK	OK	OK	OK	OK
Δ	0.63 in	0.19 in	0.58 in	0.37 in	0.65 in	0.14 in	0.25 in	0.28 in
Δ_{max}	0.67 in	0.67 in	0.67 in	0.67 in	0.67 in	0.33 in	0.33 in	0.33 in
$\Delta < \Delta_{max}$	OK	OK	OK	OK	OK	OK	OK	OK
Floor Depth	15.00 in	19.00 in	17.00 in	19.00 in	19.00 in	13.00 in	11.00 in	13.00 in
Depth < 3ft	OK	OK	OK	OK	OK	OK	OK	OK
Checks	OK	**OK**	OK	**OK**	**OK**	OK	**OK**	**OK**

Table 27: Atypical Roof Design

	Beam A	Beam B	Beam C	Beam D
Snow	35 psf	35 psf	35 psf	35 psf
DL				
Waterproofing	5 psf	5 psf	5 psf	5 psf
suspended ceiling	2 psf	2 psf	2 psf	2 psf
concrete	150 pcf	150 pcf	150 pcf	150 pcf
	5 in	5 in	5 in	5 in
	62.5 psf	62.5 psf	62.5 psf	62.5 psf
Total DL	69.5 psf	69.5 psf	69.5 psf	69.5 psf
Tributary Width	6.5 ft	13 ft	5 ft	10 ft
Beam Length	26 ft	26 ft	20 ft	20 ft
Fy	50 ksi	50 ksi	50 ksi	50 ksi
C_1	161	161	161	161
w_u	906.1 plf	1812.2 plf	697 plf	1394 plf
M_u	76.56545 ft-kips	153.1309 ft-kips	34.85 ft-kips	69.7 ft-kips
Z_{reqd}	20.42 in^3	40.83 in^3	9.29 in^3	18.59 in^3
	W18x35	W21x44	W12x22	W16x26
depth	18 in	21 in	12 in	16 in
weight	35 plf	44 plf	22 plf	26 plf
Z_x	66.5 in^3	95.8 in^3	29.3 in^3	44.2 in^3
I_x	510 in^4	847 in^4	156 in^4	301 in^4
W_u	948.1 plf	1865 plf	723.4 plf	1425.2 plf
M_u	80.11445 ft-kips	157.5925 ft-kips	36.17 ft-kips	71.26 ft-kips
Z_{reqd}	21.36 in^3	42.02 in^3	9.65 in^3	19.00 in^3
$Z_{reqd} < Z_{actual}$	OK	OK	OK	OK
Δ	0.66 in	0.78 in	0.58 in	0.59 in
Δ_{max}	0.87 in	0.87 in	0.67 in	0.67 in
$\Delta < \Delta_{max}$	OK	OK	OK	OK
Floor Depth	23.00 in	26.00 in	17.00 in	21.00 in
Depth < 3ft	OK	OK	OK	OK
Checks	OK	OK	OK	OK

Table 28: Atypical Interior Level Design

	Beam A	Beam B	Beam C	Beam D
Live Loads	80 psf	80 psf	80 psf	80 psf
DL				
Hardwood flooring	4 psf	4 psf	4 psf	4 psf
Movable steel partitions	4 psf	4 psf	4 psf	4 psf
MEP	5 psf	5 psf	5 psf	5 psf
suspended ceiling	2 psf	2 psf	2 psf	2 psf
concrete	150 pcf	150 pcf	150 pcf	150 pcf
	5 in	5 in	5 in	5 in
	62.5 psf	62.5 psf	62.5 psf	62.5 psf
Total DL	77.5 psf	77.5 psf	77.5 psf	77.5 psf
Tributary Width	6.5 ft	13 ft	5 ft	10 ft
Beam Length	26 ft	26 ft	20 ft	20 ft
Fy	50 ksi	50 ksi	50 ksi	50 ksi
C_1	161	161	161	161

w_u	1436.5 plf	2873 plf	1105 plf	2210 plf
M_u	121.3843 ft-kips	242.7685 ft-kips	55.25 ft-kips	110.5 ft-kips
Z_{reqd}	32.37 in^3	64.74 in^3	14.73 in^3	29.47 in^3

	W18x40	W24x55	W14x26	W18x35
depth	18 in	24 in	14 in	18 in
weight	40 plf	55 plf	26 plf	35 plf
Z_x	78.4 in^3	135 in^3	39.9 in^3	66.5 in^3
I_x	612 in^4	1360 in^4	243 in^4	510 in^4

W_u	1484.5 plf	2939 plf	1136.2 plf	2252 plf
M_u	125.4403 ft-kips	248.3455 ft-kips	56.81 ft-kips	112.6 ft-kips
Z_{reqd}	33.45 in^3	66.23 in^3	15.15 in^3	30.03 in^3

$Z_{reqd} < Z_{actual}$	OK	OK	OK	OK

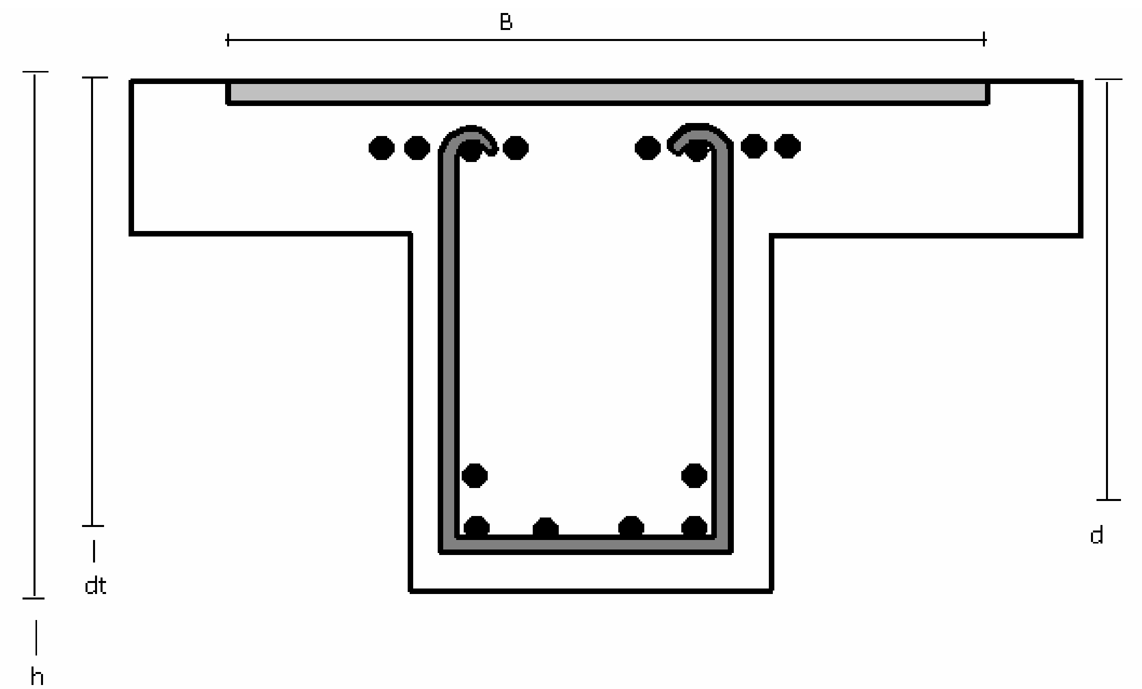
Δ	0.86 in	0.77 in	0.58 in	0.55 in
Δ_{max}	0.87 in	0.87 in	0.67 in	0.67 in
$\Delta < \Delta_{max}$	OK	OK	OK	OK

Floor Depth	23.00 in	29.00 in	19.00 in	23.00 in
Depth < 3ft	OK	OK	OK	OK

Checks	OK	OK	OK	OK

a = shear span (in)
As = area of nonprestressed tension reinforcement (in sq.)
As min =
b = effective compression flange width of T beam (in)
bw = web width
d = effective depth (in)
dt = distance from extreme compression fiber to extreme tension steel (in)
f'c = specified compressive strength of concrete (psi)
fs = calculated stress in concrete at service loads (ksi)
fy = specified yield strength of nonprestressed reinforcement (psi)
@Mn = nominal factored moment strength

Positive Moment Capacity of Beam



1) **Compute effective flange width, b.**
b cannot be greater than ¼ of the span width. So, 20'/4 = 5' = 60"
b = 60"

2) **Compute d and dt.**
Assume h of beam = 20 in and *two layers of steel in the T beam
d = h - 3.5 = 16.5 in **d = 16.5 in**
dt calculation for 6 #6 bars
dt = h – (1.5 + .375 +.75/2) = 17.75 in **dt = 17.75 in**

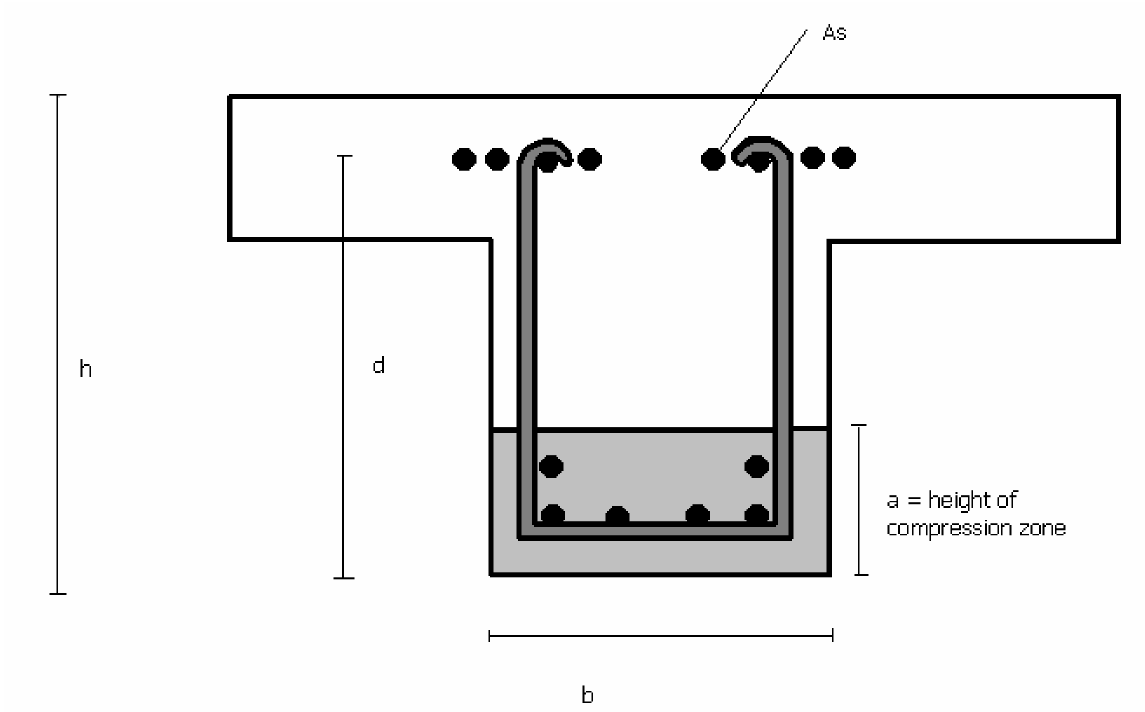
3) Compute a.
a = As(fy) / .85(f'c)b =
As based on 6 #6 bars and #3 stirrup and 2 #3 stirrup support bars
a = 2.64 (50,000) / .85 (3,000) 60 = .8627 in
a = .8627 in

4) Check As > or = As min
As min = (3 sqrt (f'c)/ fy)(b*w* d)
Assume 12" for the web width bw
As min = (3 sqrt (3,000)/ 50,000) (12" x 16.5) = .65 in sq   and
As min = 200 bw (d) / fy
As min = 200 (12)(16.5) / 50,000 = .79 in sq
Since As = 2.64 it is greater than .79 in sq

5) Check whether fs = fy
a / d = .8627 / 16.5 = .0523
a / dt = .8627 / 17.75 = .0486
tension controlled limit = .375(beta) = .319
pg 174 must check to see if .75Pb is OK
ab/d = beta(87,000 / 87,000 + fy) = .85(87,000 / 137,000) = .5398
.75(.5398) = .4048
Since .0532 < .4048, P < Pb and OK

6) Compute @Mn
@Mn = @(Asfy(d – a / 2))
= .90 (2.64 (50,000) (16.5 - .8627 / 2))) = 1,908,955
1,908,955 / 12,000 = **159.08 kips = @Mn**

Negative Moment Capacity of Beam



1) Compute b.
Since the compression zone is at the bottom of the t beam, the width of b = 12 in.
b will be arbitrarily picked to be 12 in.
b = 12 in

2) Compute d and dt
Since there is only one layer of steel in the flange we can assume:
d = h - 2.5 = 20 – 2.5 = 17.5 in **17.5 in = d**
dt = h – 2.25 = 20 – 2.25 = 17.75 in **17.75 in = dt**

3) Compute a
a = AsFy / .85 (f'c)b = As = 2 #3 stirrup support bars = pg 1054 = .73 in sq
a = .73 (50,000) / .85 (3,000) 12 in = 1.19 in **a = 1.19 in**

4) Check As > or = As min
As min = 3 sqrt(3,000) / 50,000 x 12(17.5) = .69 in sq
or 200b(d) / fy = 200 (12)(17.5) / 50,000 = .84 in sq
because As = .73 in sq and is less than .84 in sq it is **not OK**
As needs to be changed so that there is more steel with different bar combinations

3) Compute a again
a = AsFy / .85 (f'c)b = As = 8 # 6 bars = 3.52 in sq
a = 3.52 (50,000) / .85 (3,000) 12 in = 4.60 in **a = 4.60 in**

4) Check As > or = As min again

As min = 3 sqrt(3,000) / 50,000 x 12(17.5) = .69 in sq
or 200b(d) / fy = 200 (12)(17.5) / 50,000 = .84 in sq
because As = 3.52 in sq and is > .84 in sq it is **OK**

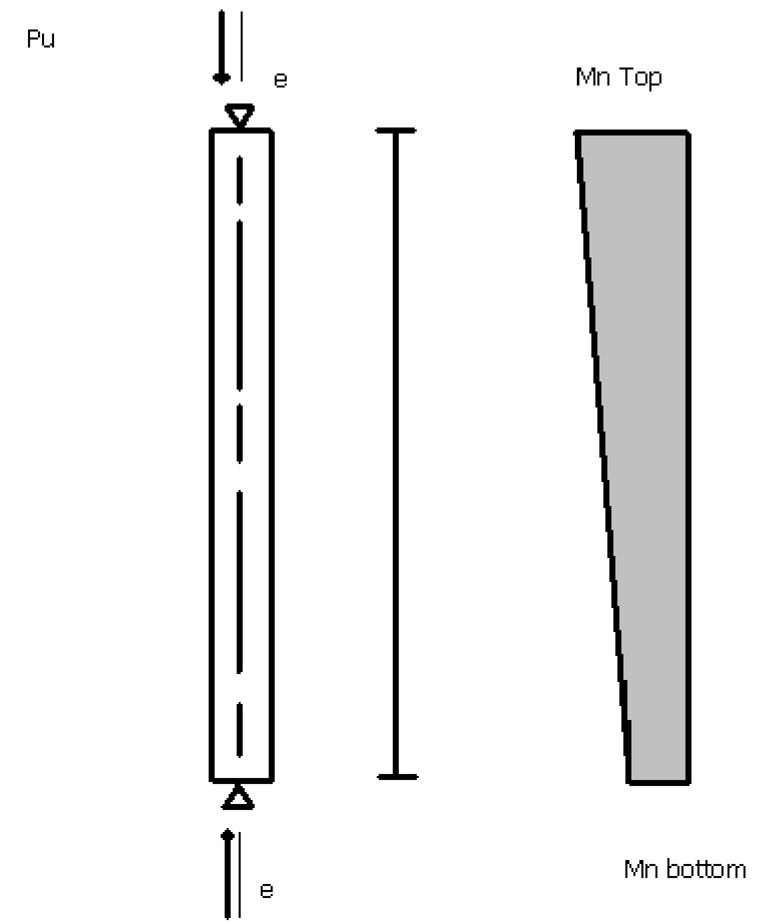
5) Check if Fs = Fy

a / dt = 4.60 / 17.5 = .263
.375 beta = .319
Since .263 < .319 the section is tension controlled and the **@ value = .90**

6) Compute @ Mn

@ Mn = @ [AsFy(d-a/2)] / 12,000 =
.90 [3.52(50,000)(17.5 – 4.6 / 2)] / 12,000 = 200.64 ft – kips
@ Mn = 200.64 ft - kips

Design of Slender Concrete Column



1) Compute the factored loads and moments and M1/M2.

Pu = 1.2DL + 1.6LL
Pu = 1.2( ) + 1.6( ) =

Moment @ top =
M= Pu(e)
M= Pu (3in/12in) =

Moment @ bottom=

M= Pu(e)
M= Pu (2in/12in) =

2) Estimate the column size.

Ag(trial) = Pu/.45(f'c + fy(*P*t)
*P*t = assumed to be .015 due to 11-18a of reinforced concrete book

Ag(trial) = Pu/.45(3,000 + 50,000(.015)   =

By determining the cross sectional area here we can pick a size column that would be satisfactory for this situation.

3) Is the column slender?

K*lu / r* < 34 – 12 (M1 / M2)

We selected a column that is 12 x 12 so, K= 1.0 and r = .3h = .3 (12)= 3.6 in

lu=column height

K*lu / r* = 1.0 x 132 / 3.6 = 36.66

34 – 12 (M1 / M2) = ?

if 36.66 exceeds the other number than the column is slender, but if there is a large difference, then the column may be too slender and inadequate

4) Check if the moments are minimum.

ACI section 10.12.3.2 shows that the column be designed with a minimum eccentricity of .6 + .3h = 1.05   where h = 1.5 for some reason

Check is good so use step 1 moments in design

5) Compute EI

EI = .4 (Ec)Ig / 1 + *B*d

Ec = M@ top (sqrt(f'c)) =

Ig = bh^3 / 12 = 15 (15)^3 / 12 = 4220 in ^4

*B*d = factored dead load to total factored load

*B*d = 1.2 (DL) / total load

EI = (Ec)Ig / 2.5(1 + *B*d) =

6) Compute the Magnified Moment.   Pg 554

Mc = dns(M2)

dns = Cm / 1 – Pu / .75(Pc) and is greater than or = to 1.0

Cm= .6 + .4 (M1/M2) =

Pc = Pi ^2 (EI) / K*lu*^2 =

dns = between 1.75 and 2 then a large cross section should be selected

C. Cost Estimates

Table 29: Substructure Cost (Volume)

	VOLUME (cu. inches)							
	Beam		Girder		Column		TOTAL	
Scenario	Concrete	Steel	Concrete	Steel	Concrete	Steel	Concrete	Steel
1	8294400	69120	7188480	55680	500035	4542	15982915	129342
2	6220800	72000	7188480	23040	833392	7569	14242672	102609
3	5391360	100800	16404480	130560	434391	3946	22230231	235306

	VOLUME			COST
	in3	ft3	yard	$100/yard
Layout	Concrete	Concrete	Concrete	Concrete
1	15982915	110992	4111	411083
2	14242672	98907	3663	366324
3	22230231	154377	5718	571765

	VOLUME		WEIGHT		COST
	in3	ft3	490lb/ft3	Tons	$800/ton
Layout	Steel	Steel	Steel	Steel	Steel
1	129342	898	440122	220	176049
2	102609	713	349156	175	139662
3	235306	1634	800694	400	320278

COST	Concrete	Steel	Total	TOTAL $
1	411083	176049	587132	$587,000
2	366324	139662	505986	$506,000
3	571765	320278	892043	$892,000

Table 30: Cost Breakdown by CSI Division

Division 1 General Requirements	SQ FT	#	Unit Cost	Cost
			1%	
Contractor Fees				
Requirements		10%	66878	668780
Overhead		5%	66878	334390
Profit		10%	66878	668780
Architect Fees				
Design Fees		7%	66878	468146
			TOTAL	2140096

Division 2 Site Construction	SQ FT	#	Unit Cost	Cost
TOTAL Site Preparation	15000		0.22	3300
Basic Site Materials and Methods				
Site Remediation				
Site Preparation				
Earthwork				
Utility Services				
Drainage and Containment				
Bases, Ballasts, Pavements				
Parking Lot- 6" Base, 2" Binder, 1" Topping	13560		2.04	27662.4
Side Walk- 4" Thick Concrete Broomed Finish	5696		3.85	21929.6
Curbs- Asphaltic 8" wide and 6" Tall	584 LF		2.55	1489.2
Planting				
Site Restoration				
Loam and Top Soil	37 CY		53.5	1979.5
Grass- Sod	22200		445	9879
Landscaped Area	*			
			TOTAL	66239.7

Division 3 Concrete	SQ FT	#	Unit Cost	Cost
Floor Slabs	869 CY		150	130350
Partial Basement Walls 4" Thick	248		61	15128
Standard Foundation w/ Footings	13156		0.93	12235.08
			TOTAL	157713.1

Division 4 Masonry	SQ FT	#	Unit Cost	Cost

Brick and Mortar Exterior Walls	29376		7.52	220907.5
			TOTAL	220907.5

Division 5 Metals	SQ FT	#	Unit Cost	Cost
Sub Structure *See Steel Section				538000
Metal Decking	52624		2	105248
Non Supporting Wall Studs 24' OC	144576		1.5	216864
			TOTAL	860112

Division 6 Woods and Plastics	SQ FT	#	Unit Cost	Cost
Basic Woods and Plastics Materials and Methods				
6052				
Wall Cabinets 2 Bay 36" Wide		48	222	10656
Base Kitchen Cabinets 30"		24	256.5	6156
Trim Boards	16064 LF		0.57	9156.48
6090				
Flooring Nails	N/A			
Sheet Metal Screws	N/A			
Wood Screws	N/A			
Finish Carpentry				
6220				
Base Moldings Stock Pine	LF	5176	2.67	13819.92
Ceiling Moldings Stock Pine	LF	5176	1.66	8592.16
Door Moldings Pine Trim		72	60.95	4388.4
6270				
Shelving - Book Cases		24	39.24	941.76
Architectural Woodwork				
6410				
4 drawer 27" wide	1/apt	24	286	6864
6415				
Counter Tops Kitchen	7.25 LF	24	17.9	3114.6
Bathroom Counter Tops	2.5 LF	24	17.9	1074
Public Restroom Counter Tops	6 LF	2	17.9	214.8
6430				
Railings	14.42 LF	24	59.29	20519.08
Brackets and Balusters	*			
Stairs Prefabricated	13	24	9.15	2854.8
Stair Risers @ 8' (13)	13	24	340	106080
			TOTAL	194432

Division 7 Thermal and Moisture Protection	SQ FT	#	Unit Cost	Cost

Basic Materials and Methods				
7110				
Water Proofed Portland Cement	52624		5.5	289432
7160				
Cementitious Spray On Proofing	52624		2.97	156293.3
Thermal Protection				
7210				
Masonry Loose Fill Insulation	27456		0.82	22513.92
7220				
Shingles, Roof Tiles, Roof Coverings				
roof w/ metal joists and decking	13156	1	1.14	14997.84
roof coverings- tar and gravel w/ flashing	13156	1	0.72	9472.32
decking insulation	13156	1	0.64	8419.84
Roof Specialties and Accessories				
7710				
Downspouts	44	11	1.02	493.68
Drip Edge	N/A			
Elbows		22	5.86	128.92
Gutters	664 LF		0.7	464.8
7720				
Snow Guards	N/A			
Smoke Vent		2	1675	3350
Fire and Smoke Protection				
7812				
Spray On Fire Proofing				
7840				
Metallic Piping, Beams and Joists				30000
Beams				
Joists				
Decking	52624		0.8	42099.2
Floor Slabs	52624		1.2	63148.8
Joint Sealers				
7920				
Caulking and Sealants	N/A			
			TOTAL	640814.6

Division 8 Doors and Windows	SQ FT	#	Unit Cost	Cost
Metal Doors and Frames				
8110				
Steel Flush Full Panel Door	Apt Exit	32	203	6496
Steel Insulated 4' x 8' Full Panel Doors	Exits	9	233	2097
Wood and Plastic Doors				
8210				
Pre-Hung Wood Interior Doors Oak Face	Interior	72	321	23112
Specialty Doors				
8340				

Swinging Glass Door pairs 6' x 7'	*	2	5000	2000
Windows				
4 x 4 Sliders	1	112	173.6	19443.2
Double Hung 2' x 3'2"	1	192	140	26880
Hardware				
8710				
Automatic Commercial Door Openers	*	2	7025	14050
Locksets for Apartment Doors		48	55	2640
8720				
Rubber Threshholds		56	42.5	2380
Glazing				
8810				
Floating Insulated Tinted Glass 3/4"	2496		24	59904
			TOTAL	159002.2

Division 9 Finishes	SQ FT	#	Unit Cost	Cost
Suspended 5/8" Fiberglass Ceiling	52624		2.85	149978.4
Painted 5/8" Drywall	16064		3.32	53332.48
Carpet	51376		0.55	28256.8
Tile flooring	140	24	11.1	37296
Prefinished Oak Strip Flooring	1888		5.76	10874.88
			TOTAL	279738.6

Division 10 Specialties	SQ FT	#	Unit Cost	Cost
Compartments and Cubicles				
10160				
Bathroom Stalls		2	543.5	1087
Access Flooring				
10275				
Air Conditioning Grilles	10/ap	250	24	6000
Flagpoles				
10355				
Aluminum Tapered Flagpole 20'		1	1152	1152
Fire Protection Specialties				
10520				
Fire Extinguishers 10 lb		30	80	2400
Telephone Specialties				
10750				
Telephones in Apartments	2/ap	54	40	2160
Telephone Booth Outside Lobby		1	1533	1533
Pay Phone Inside Lobby		1	900	900
Toilet/Bath/Laundry Accessories				
10810				
Toilet Paper Curtain Rod		52	17	884

Soap Dispenser Unit		4	54	216
Waste Receptacle	Aug-72	80	50$/14$	1408
Towel Holder		48	24	1152
Mirrors		28	60	1680
10820				
Medicine Cabinet		24	89	2136
Wardrobe and Closet Specialties				
10905				
Wall Mounted Coat Rack		48	18	864
			TOTAL	23572

Division 11 Equipment	SQ FT	#	Unit Cost	Cost
Commercial Laundry				
11119				
Commercial Washers		16	1325	21200
Commercial Double Stacked Dryers		8	6325	50600
Audio - Visual				
11136				
Projection Screen 25SF		1	840	840
Dolby Small Sound System		1	3185	3185
Solid Waste Handling				
111790				
Waste Compactor 3 CY		1	14225	14225
Fluid Waste and Disposal				
11310				
GRAVITY				
Food Service				
11405				
Freezer and Refrigerator 15.9 CF		24	860	20640
11420				
GE JKP20 Electric Single Oven Bake		24	800	19200
Counter Top Stove		24	440	10560
11440				
Dishwasher 2 Cycle		24	500	12000
Garbage Disposal		24	148	3552
Residential				
11460				
Unit Shower		24	824	19776
			TOTAL	175778

Division 12 Furnishings	SQ FT	#	Unit Cost	Cost
Furnishings and Accessories				
12460				
Trash Recepticle		24	15	360

12483				
Floor Mats		48	15	720
12492				
Blinds		304	81	24624
Furniture				
12510				
Office Chairs		20	160	3200
Conference Chairs		2	172	344
12560				
Oak Six Drawer Dresser		96	239	22944
Bed Side Tables		96	98	9408
Other				
Kitchen Table		24	380	9120
4 Chairs		96	90	8640
3 Seater Sleeper Couches		48	150	7200
Futon		24	380	9120
Personal Oak Desks		96	679	65184
Leatherette Mid-Back Chair Desk Chairs		96	98	9408
Bathroom Vanities 30"		48	176.6	8476.8
Full Size Beds		96	400	38400
Bed Frames		96	89	8544
TV Stand		24	71	1704
Computer Lab Tables		6	360	2160
Computers	12		1500	18000
Printers	2		2400	4800
Vending Machines	10		2600	26000
			TOTAL	278356.8

Division 13 Special Construction	SQ FT	#	Unit Cost	Cost
Security Access and Surveillance				
13710				
Card Access Control		9	350	3150
Detection and Alarm				
13720				
Master Box Fire Alarm		9	91	819
Smoke Detectors		147	127	18669
Fire Suppresion				
13930				
Sprinkler System Components	52624		1.73	91039.52
Stand Pipes	52624		0.33	17365.92
Other				
Parking Signs	24		73	1752
			TOTAL	132795.4

Division 14 Conveying Systems	SQ FT	#	Unit Cost	Cost

Elevators				
Elevator System up to 50'		1	147900	147900
Interior Stairs- Concrete 36'	1		4000	4000
Exterior Stairs- Concrete 36', 10' wide	2		4000	8000
			TOTAL	159900

Division 15 Mechanical	SQ FT	#	Unit Cost	Cost
Plumbing	52624		7.64	402047.4
Kitchen/Bathroom Service Fixture and Supplies				
Toilets		50	1110	55500
Urinals		2	1030	2060
Bathroom Sinks		52	1190	61880
Kitchen Sinks		24	970	23280
Water Coolers		5	244.5	1222.5
Domestic Water Distribution	52624		2.34	123140.2
Rain Water Drainage	13156		0.15	1973.4
Heating	52624		4.72	248385.3
Hot Water and Baseboard Radiation				
Boilers				
Cooling				
Chilled Water and Air Cooled System	52624		6.52	343108.5
			TOTAL	1262597

Division 16 Electrical	SQ FT	#	Unit Cost	Cost
Service and Distribution				
1600 Amp Service with Panel Boards and Feeders	52624		1.78	93670.72
Lighting and Power				
Light Fixture, Branch Wiring, Switches	52624		5.76	303114.2
Exterior Building Lights- Quartz 500 Watt	8		154	1232
Light Poles- 20' High	9		1550	13950
Special Electrical				
Alarm Systems and Emergency Lighting	52624		0.35	18418.4
Emergency Generator	52624		0.14	7367.36
			TOTAL	437752.7

Table 31: Final Cost Analysis

DIVISION	COST	%
Division 1 General Requirements	2326452	31.54
Division 2 Site Construction	66239.7	0.90
Division 3 Concrete	157713.1	2.14
Division 4 Masonry	220907.5	2.99
Division 5 Metals	860112	11.66
Division 6 Woods and Plastics	194432	2.64
Division 7 Thermal and Moisture Protection	640814.6	8.69
Division 8 Doors and Windows	159002.2	2.16
Division 9 Finishes	279738.6	3.79
Division 10 Specialties	23572	0.32
Division 11 Equipment	175778	2.38
Division 12 Furnishings	278356.8	3.77
Division 13 Special Construction	132795.4	1.80
Division 14 Conveying Systems	159900	2.17
Division 15 Mechanical	1262597	17.12
Division 16 Electrical	437752.7	5.93
TOTAL COST ($)	$7,376,164	100.00

D. LEED Certification & Cost

LEED

Project Checklist

Sustainable Sites

14 Possible Points

Y	?	N	Item	Description	Points
Y			Prereq 1	**Erosion & Sedimentation Control**	Required
●	?	N	Credit 1	**Site Selection**	1
●	?	N	Credit 2	**Urban Redevelopment**	1
Y	?	N	Credit 3	**Brownfield Redevelopment**	1
●	?	N	Credit 4.1	**Alternative Transportation**, Public Transportation Access	1
Y	?	N	Credit 4.2	**Alternative Transportation**, Bicycle Storage & Changing Rooms	1
Y	?	N	Credit 4.3	**Alternative Transportation**, Alternative Fuel Vehicles	1
●	?	N	Credit 4.4	**Alternative Transportation**, Parking Capacity	1
●	?	N	Credit 5.1	**Reduced Site Disturbance**, Protect or Restore Open Space	1
Y	?	N	Credit 5.2	**Reduced Site Disturbance**, Development Footprint	1
Y	?	N	Credit 6.1	**Stormwater Management**, Rate and Quantity	1
Y	?	N	Credit 6.2	**Stormwater Management**, Treatment	1
●	?	N	Credit 7.1	**Heat Island Effect**, Non-Roof	1
●	?	N	Credit 7.2	**Heat Island Effect**, Roof	1
●	?	N	Credit 8	**Light Pollution Reduction**	1

Water Efficiency

5 Possible Points

Y	?	N	Item	Description	Points
●	?	N	Credit 1.1	**Water Efficient Landscaping**, Reduce by 50%	1
●	?	N	Credit 1.2	**Water Efficient Landscaping**, No Potable Use or No Irrigation	1
Y	?	N	Credit 2	**Innovative Wastewater Technologies**	1
●	?	N	Credit 3.1	**Water Use Reduction**, 20% Reduction	1
●	?	N	Credit 3.2	**Water Use Reduction**, 30% Reduction	1

Energy & Atmosphere

17 Possible Points

Y	?	N	Item	Description	Points
Y			Prereq 1	**Fundamental Building Systems Commissioning**	Required
Y			Prereq 2	**Minimum Energy Performance**	Required
Y			Prereq 3	**CFC Reduction in HVAC&R Equipment**	Required
●	?	N	Credit 1	**Optimize Energy Performance**	1–10
●	?	N	Credit 2.1	**Renewable Energy**, 5%	1
●	?	N	Credit 2.2	**Renewable Energy**, 10%	1
Y	?	N	Credit 2.3	**Renewable Energy**, 20%	1
●	?	N	Credit 3	**Additional Commissioning**	1
●	?	N	Credit 4	**Ozone Depletion**	1
Y	?	N	Credit 5	**Measurement & Verification**	1
Y	?	N	Credit 6	**Green Power**	1

LEED™ Rating System Version 2.1

LEED

Materials & Resources

13 Possible Points

Y	?	N			
Y			Prereq 1	Storage & Collection of Recyclables	Required
			Credit 1.1	**Building Reuse**, Maintain 75% of Existing Shell	1
			Credit 1.2	**Building Reuse**, Maintain 100% of Shell	1
			Credit 1.3	**Building Reuse**, Maintain 100% Shell & 50% Non-Shell	1
●			Credit 2.1	**Construction Waste Management**, Divert 50%	1
●			Credit 2.2	**Construction Waste Management**, Divert 75%	1
●			Credit 3.1	**Resource Reuse**, Specify 5%	1
●			Credit 3.2	**Resource Reuse**, Specify 10%	1
●			Credit 4.1	**Recycled Content**, Specify 5% (p.c. + ½ p.i.)	1
			Credit 4.2	**Recycled Content**, Specify 10% (p.c. + ½ p.i.)	1
●			Credit 5.1	**Local/Regional Materials**, 20% Manufactured Locally	1
			Credit 5.2	**Local/Regional Materials**, of 20% in MRc5.1, 50% Harvested Locally	1
			Credit 6	**Rapidly Renewable Materials**	1
●			Credit 7	**Certified Wood**	1

Indoor Environmental Quality

15 Possible Points

Y	?	N			
Y			Prereq 1	Minimum IAQ Performance	Required
Y			Prereq 2	Environmental Tobacco Smoke (ETS) Control	Required
●			Credit 1	**Carbon Dioxide (CO_2) Monitoring**	1
			Credit 2	**Ventilation Effectiveness**	1
			Credit 3.1	**Construction IAQ Management Plan**, During Construction	1
●			Credit 3.2	**Construction IAQ Management Plan**, Before Occupancy	1
●			Credit 4.1	**Low-Emitting Materials**, Adhesives & Sealants	1
●			Credit 4.2	**Low-Emitting Materials**, Paints	1
●			Credit 4.3	**Low-Emitting Materials**, Carpet	1
●			Credit 4.4	**Low-Emitting Materials**, Composite Wood	1
			Credit 5	**Indoor Chemical & Pollutant Source Control**	1
●			Credit 6.1	**Controllability of Systems**, Perimeter	1
			Credit 6.2	**Controllability of Systems**, Non-Perimeter	1
			Credit 7.1	**Thermal Comfort**, Comply with ASHRAE 55-1992	1
			Credit 7.2	**Thermal Comfort**, Permanent Monitoring System	1
			Credit 8.1	**Daylight & Views**, Daylight 75% of Spaces	1
			Credit 8.2	**Daylight & Views**, Views for 90% of Spaces	1

Innovation & Design Process

5 Possible Points

Y	?	N			
			Credit 1.1	**Innovation in Design**	1
			Credit 1.2	**Innovation in Design**	1
			Credit 1.3	**Innovation in Design**	1
			Credit 1.4	**Innovation in Design**	1
			Credit 2	**LEED™ Accredited Professional**	1

Project Totals

69 Possible Points

Certified 26-32 points **Silver** 33-38 points **Gold** 39-51 points **Platinum** 52-69 points

U.S. Green Building Council

LEED Certification Costs

Table 32: LEED Points

	LEED	POINTS
	Bike Racks for 16 people	1
	reducing heat island effect	1
	reflective roof top	1
	water use reduction by 30%	2
	energy reduction 25%	3
	10% renewable energy	2
	ozone protection	1
	CO_2 detectors	1
free	low emmiting adhesives and sealants	1
free	paint and coatings	1
free	low emmiting carpet	1
	motion detectors and operable windows	1
free	site selection	1
free	development density	1
free	alternative transportation	1
free	restoring open space	1
free	make sure that project manager is LEED accredited	1
free	recycling 75% of waste during construction	2
free	developing an indoor air quality flushing	1
	5 carpool parking spaces	1
free	efficient angling of lights onto property	1
free	no irrigation system	2
free	reuse 5% building materials	1
free	using 10% recycled materials	2
free	certified wood	1
free	20% materials must come from within 500 miles	1
	SILVER ACCREDITED TOTAL POINTS	33

Table 33: LEED Cost Analysis

	Cost	#	New $	Original $	TOTAL $	DIVISION
16 Person Bike Rack - 10' Rack	561	2	1122	0	1122	2
Reduce Heat Island Effect						
Roof- Light Colored Gravel						
Pavement- Portland Cement Concrete 10" thick	4.94	13560 sf	66986.4	27662	39324	2
Water Use Reduction						
Kitchen Faucets	600	24	14400	4800	9600	15
Bathroom Faucets	250	52	13000	7280	5720	15
Toilets						
Dishwasher	270	24	6480	12000	5520	11
Washer (clothes) NO COINS	760	16	12160	21200	9040	11
Shower Head	75	24	1800	960	840	15
10% Renewable Energy						
Solar Panels	1000	20	20000	0	20000	13
Energy System Collector- Storage Tank	1125	1	1125	0	1125	13
Ozone Protection						
HVAC	14.12	52624	743220	591494	151726	15
Refrigerators- 18.4 cu ft	739	24	17736	20640	2904	11
Co2 Detectors	59.7	147	8776	0	8776	13
Low Emitting Adhesives and Sealants						
Low Emitting Paints and Coatings						
Low Emitting Carpet						
Motion Detectors and Operating Windows	19.95	263	5249	0	5249	13
Energy Saving						
Light Bulbs 100 watt (12X)	8	500	4000	185	3815	16
Refrigerators- 18.4 cu ft						
Dish Washer						
Washer (clothes) NO COINS						
Dryer (clothes) NO COINS	860	16	13760	6325	7435	11
5 Carpool Parking Spaces	73	5	365	0	365	13

COST	255098
SAVINGS	17464
TOTAL $	237634

E. Lot Location

Figure 14: Topographical Map

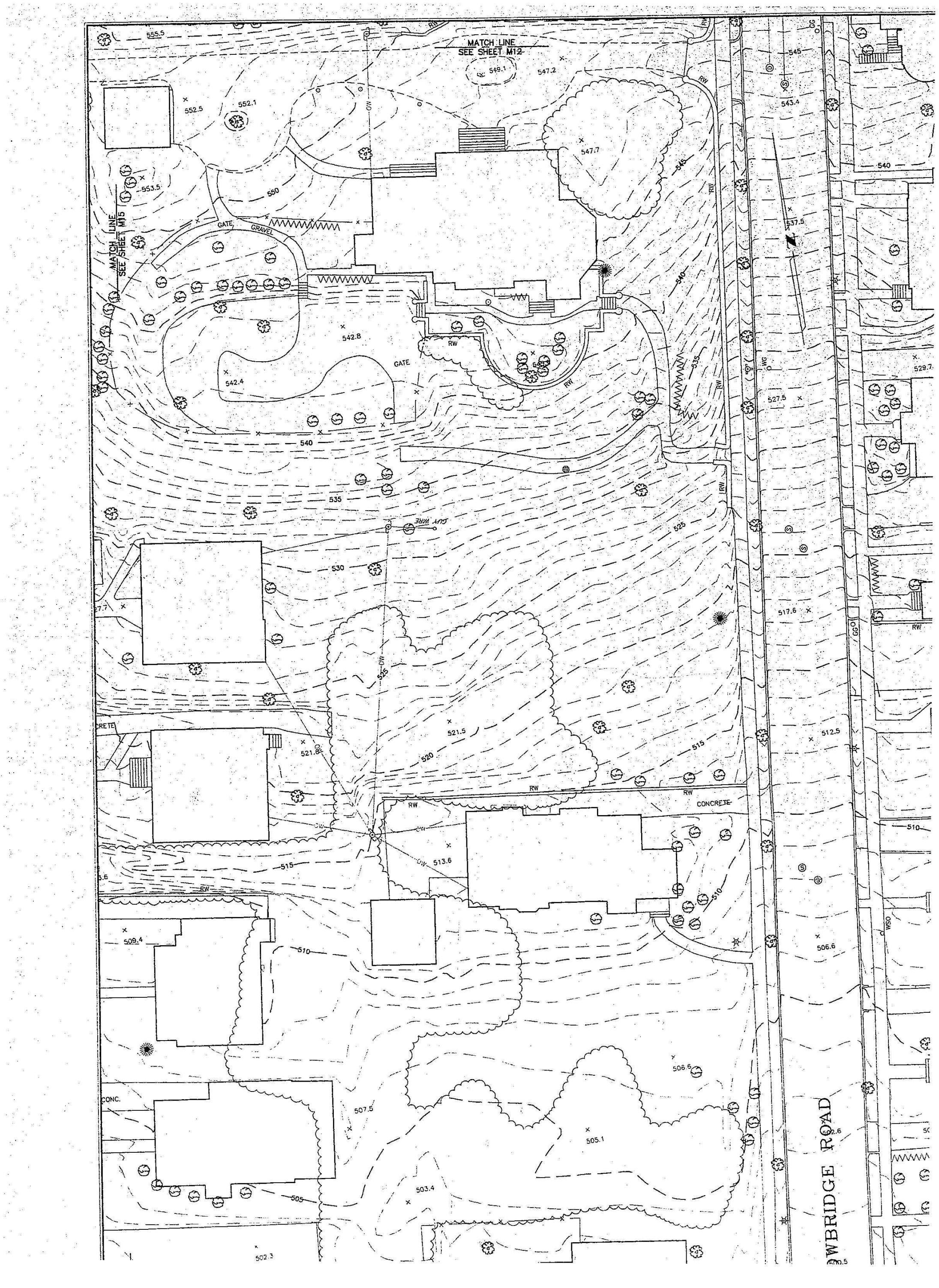


Figure 15: Floor Plan Layout

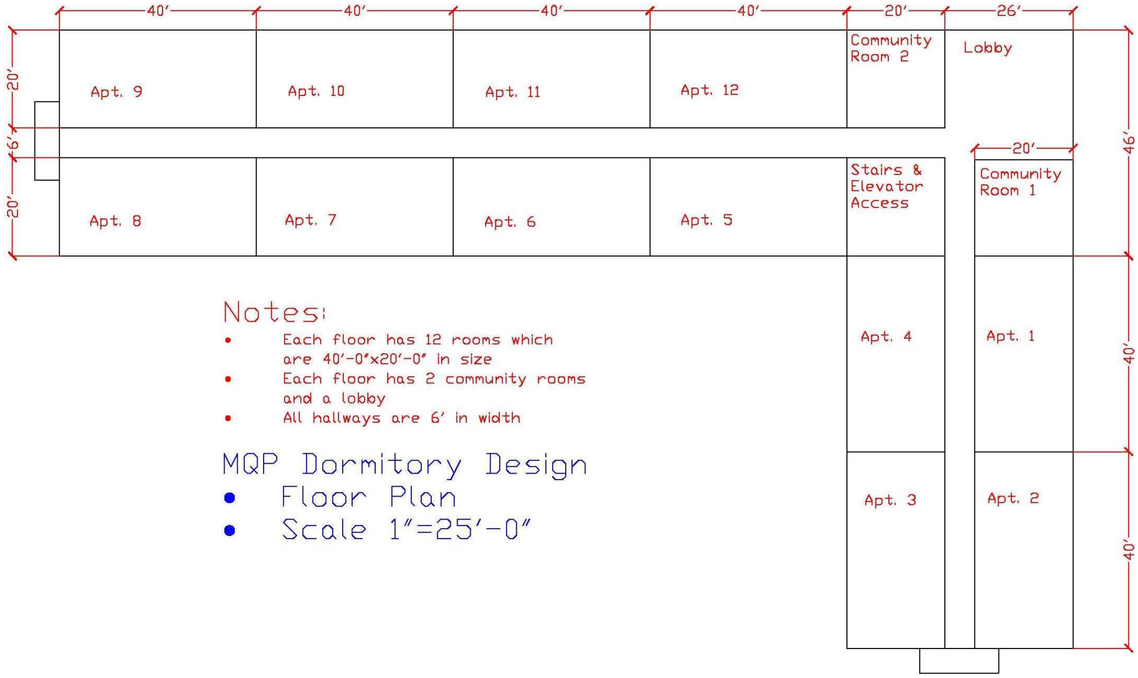
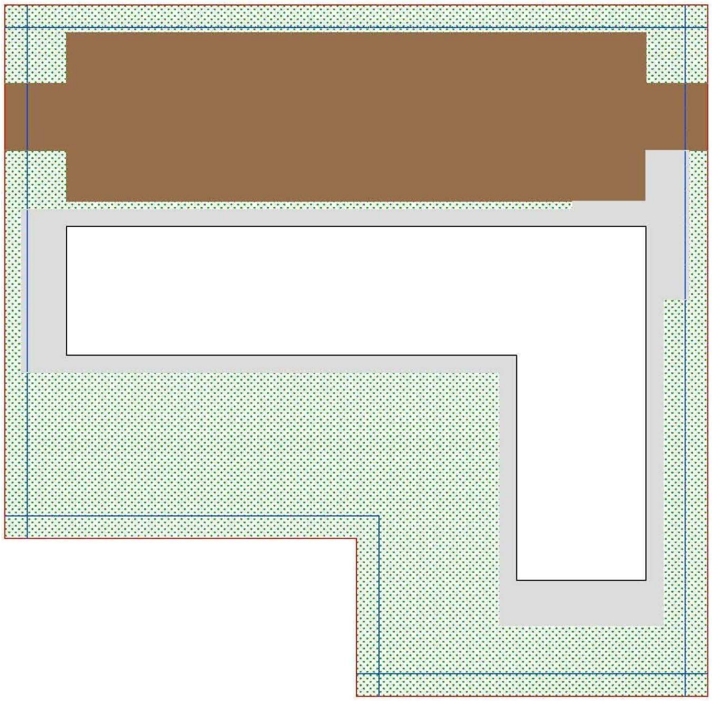


Figure 16: Site Plan Layout



References

Fornier, D & Maves, M & Chapman, M & Chlarson, J & Eichel, A & Epsten D (2005, October) *LEED-NC Application Guide for Multiple Buildings and On-Campus Building Projects.* Retrieved February 4, 2007, from https://www.usgbc.org/ShowFile.aspx?DocumentID=1097

MacGregor, J. G., Wight J. K., (2005) *Reinforced Concrete Mechanics and Design* (4th ed.) New Jersey: Pearson Education, Inc., Upper Saddle River

McCormac, J.C., & Nelson, Jr. J.K. (2003) *Structural Steel Design, LRFD Method.* New Jersey: Upper Saddle River.

Oberlender, G.D. (2000) *Project Management for Engineering and Construction.* Second Edition. United States of America.

Reed Construction Data Inc. (2007) *RS Means Interior Cost Data.* 24th Annual Edition. Massachusetts, Kingston

Reed Construction Data Inc. (2007) *RS Means Building Construction Cost Data.* 65th Annual Edition. Massachusetts, Kingston

Thornton, W. A, Holland, M. V., Barger, B. L., Carter, C. J., Cole, H. A., & Davis, B. (December 2005) *AISC Steel Construction Manual* (13th ed.) Printed in the United States of America